Autonomous Target Selection and Observation for Curiosity and Mars 2020 Rovers

Vandi Verma
NASA Jet Propulsion Laboratory, California Institute of Technology
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AEGIS & Autonomous Robotic Arm Positioning

AEGIS
Tara Estlin
Daniel Gaines
Raymond Francis
Gary Doran
Vandi Verma

Curiosity ChemCam
Roger Wiens
Steven Johnstone
Suzi Montaño
Olivier Gasnault
Laurent Peret
Eric Lorigny
Diana Blaney
Jens Frydenvang

M2020 Autonomous Arm Positioning
Jeffrey Biesiadecki
Joseph Carsten
Vandi Verma

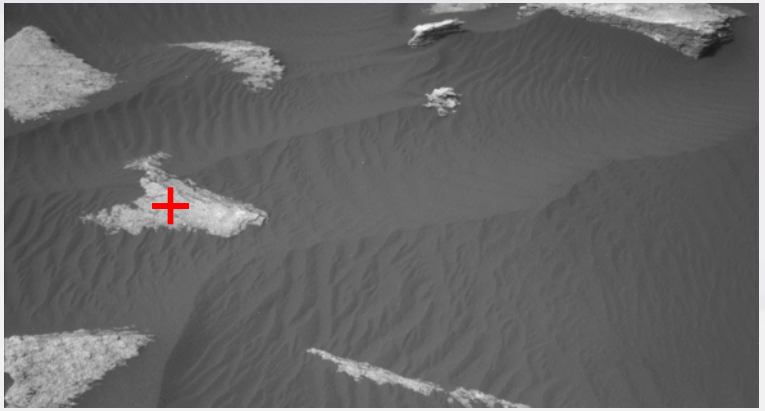
Texture Cam
David Thompson

Curiosity AEGIS Operations
Deb Chattopadhyay
Betina Pavri

AEGIS: Autonomous Targeting

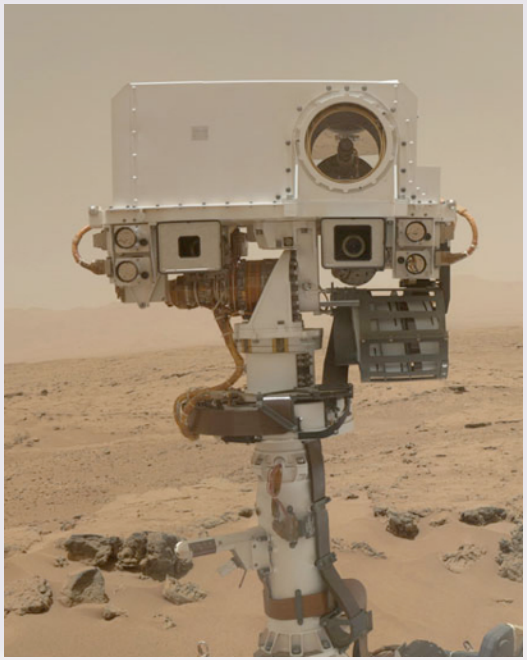
Autonomous Exploration for Gathering Increased Science

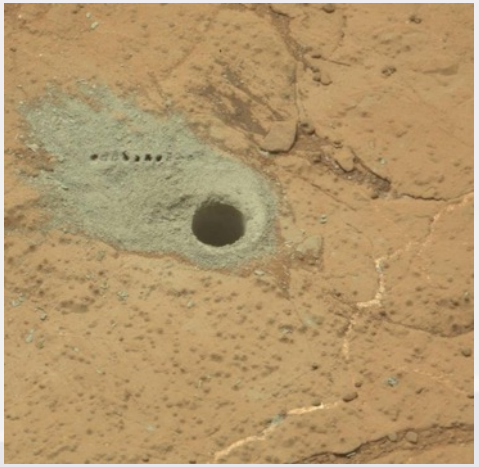
- An **intelligent software** system
- Running since 2016 **on-board** the *Curiosity* rover. Will be on *Mars 2020 rover*.
- **Autonomously chooses science targets** and measures them with the ChemCam laser spectrometer instrument
- Favours targets based on **scientists' preferences**
- Regularly, reliably interprets **complex natural scenes**
- Has **consistently performed well** even in unexplored terrain



ChemCam Instrument

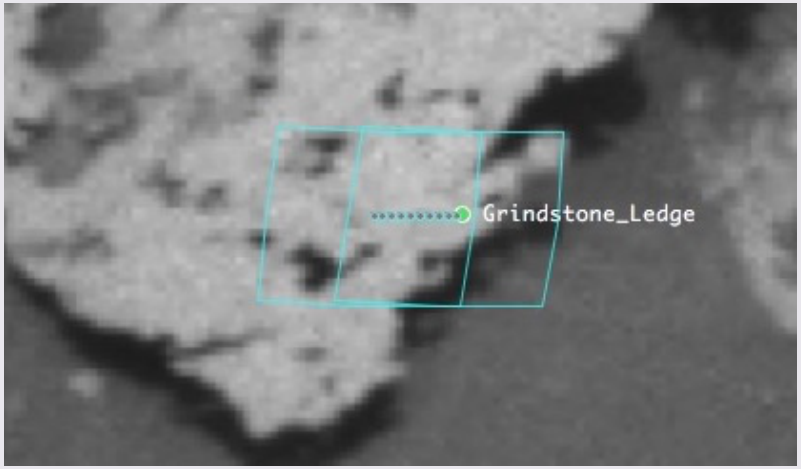
- Chemistry and Camera (Chemcam)
  - Laser-Induced Breakdown Spectrometer (LIBS). Rasters typically have a spacing of 1 mrad.
  - Remote Micro-Imager (RMI). Narrow-field (20 mrad diameter).
- Gives geochemical composition of rock targets at ranges up to 7 metres
- Over 440,000 measurements on 1500 targets on Mars since 2012

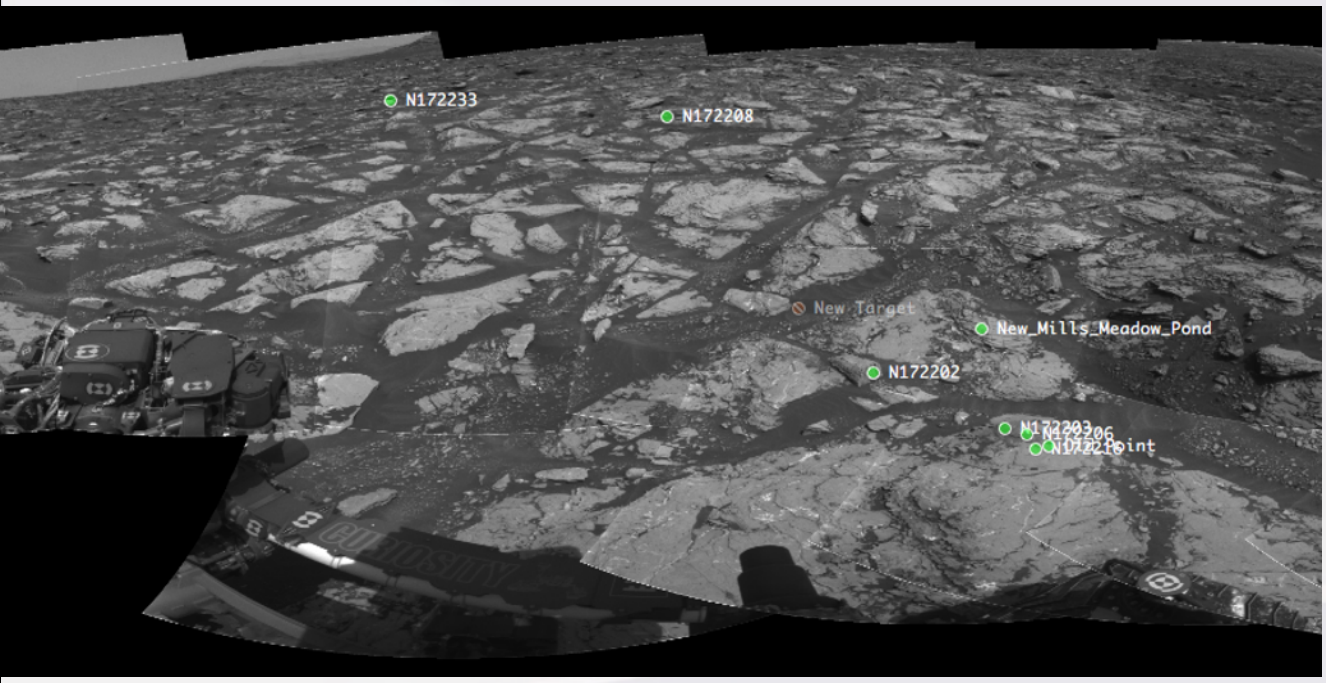


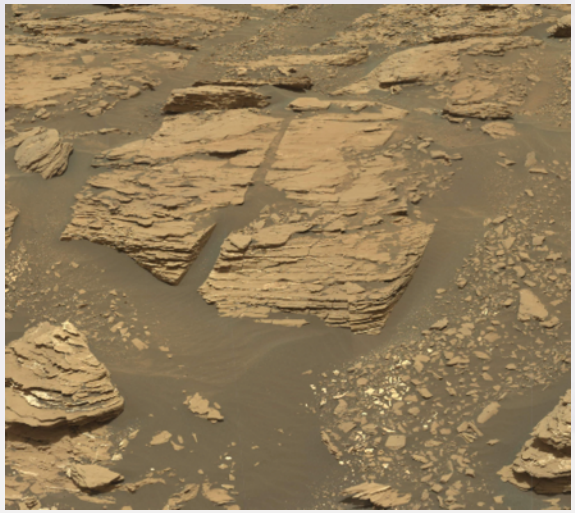


ChemCam Targeting

- Targets selected by specialists on Earth, inspecting images returned from Mars
- NavCam, sometimes MastCam or MAHLI
- Choose suitable science targets at each location
- Ensure proper focus and raster size/shape

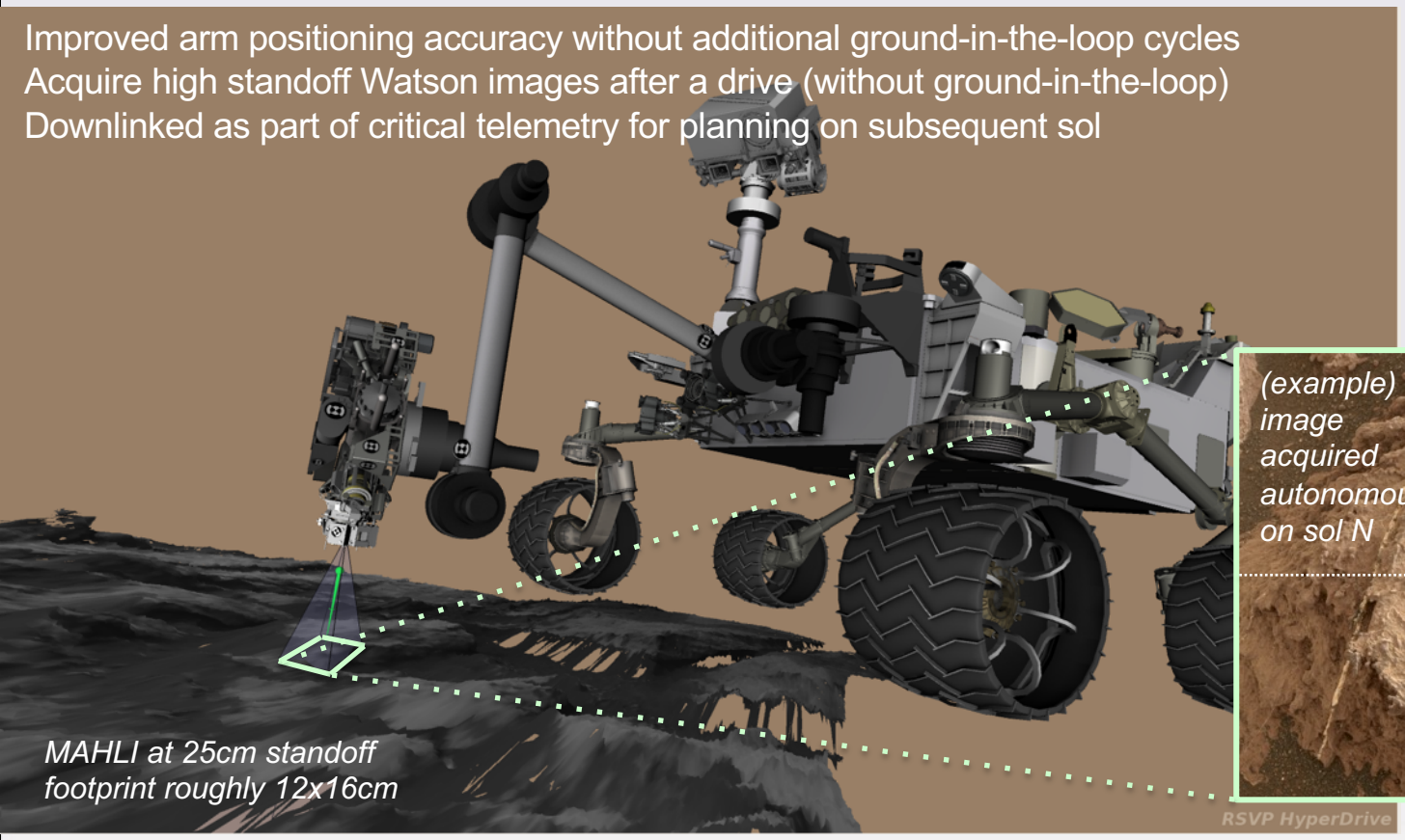


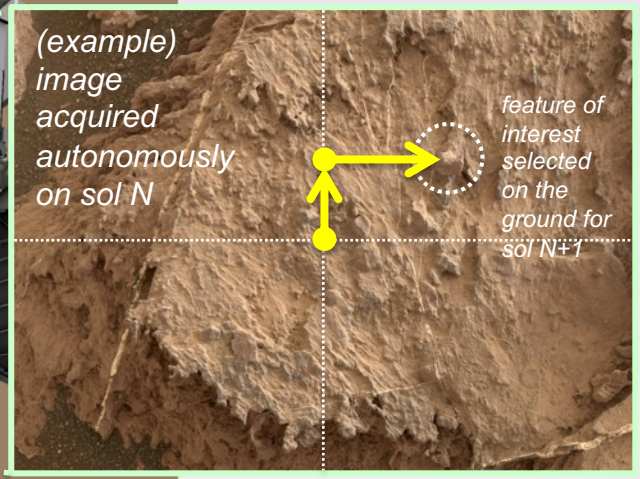




Autonomous Robotic Arm Positioning

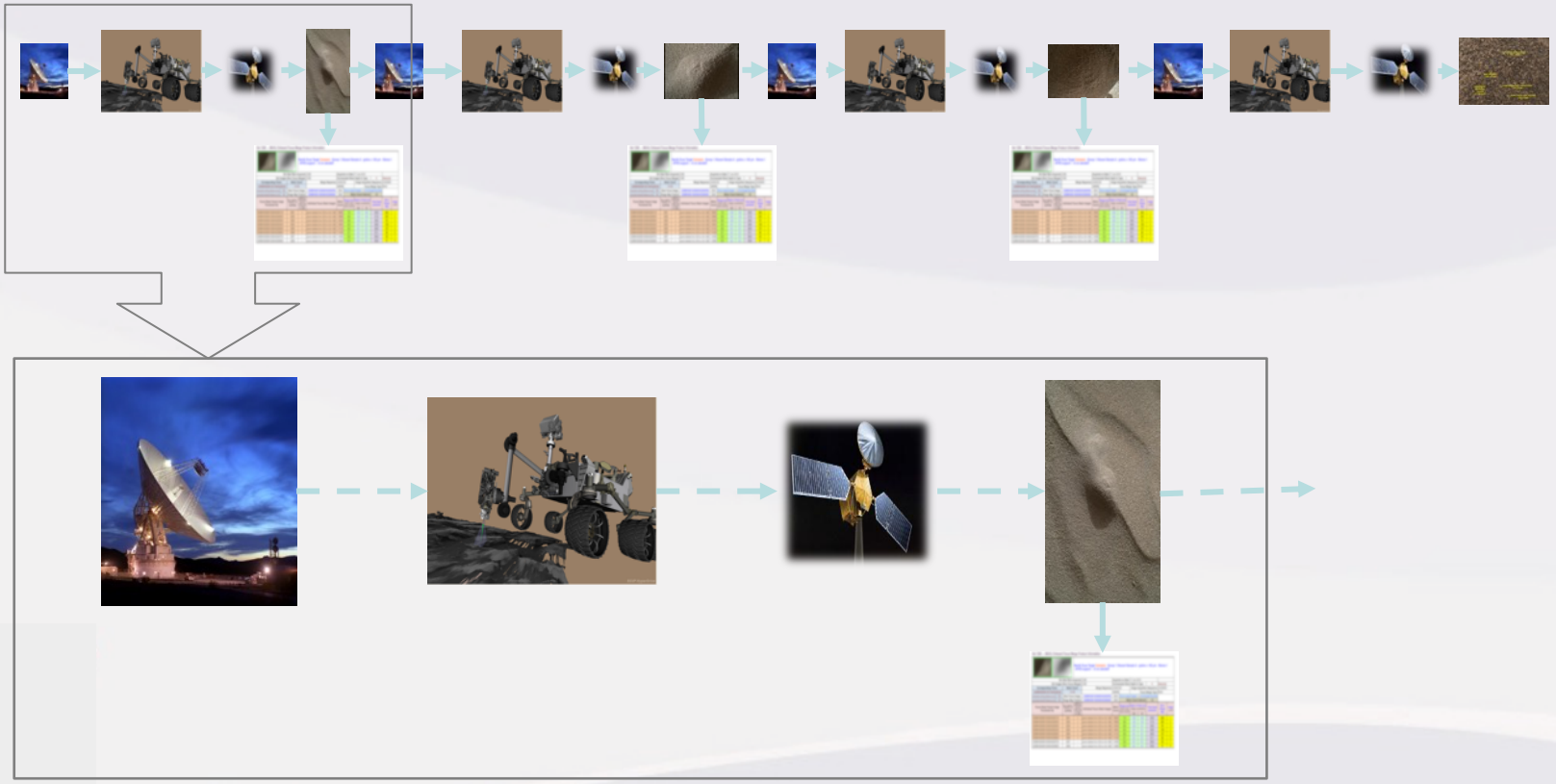
Improved arm positioning accuracy without additional ground-in-the-loop cycles
Acquire high standoff Watson images after a drive (without ground-in-the-loop)
Downlinked as part of critical telemetry for planning on subsequent sol





Iteratively inchworm closer for highest accuracy

Closest approach Curiosity MAHLI use multiple ground in the loop cycles Sol 1241

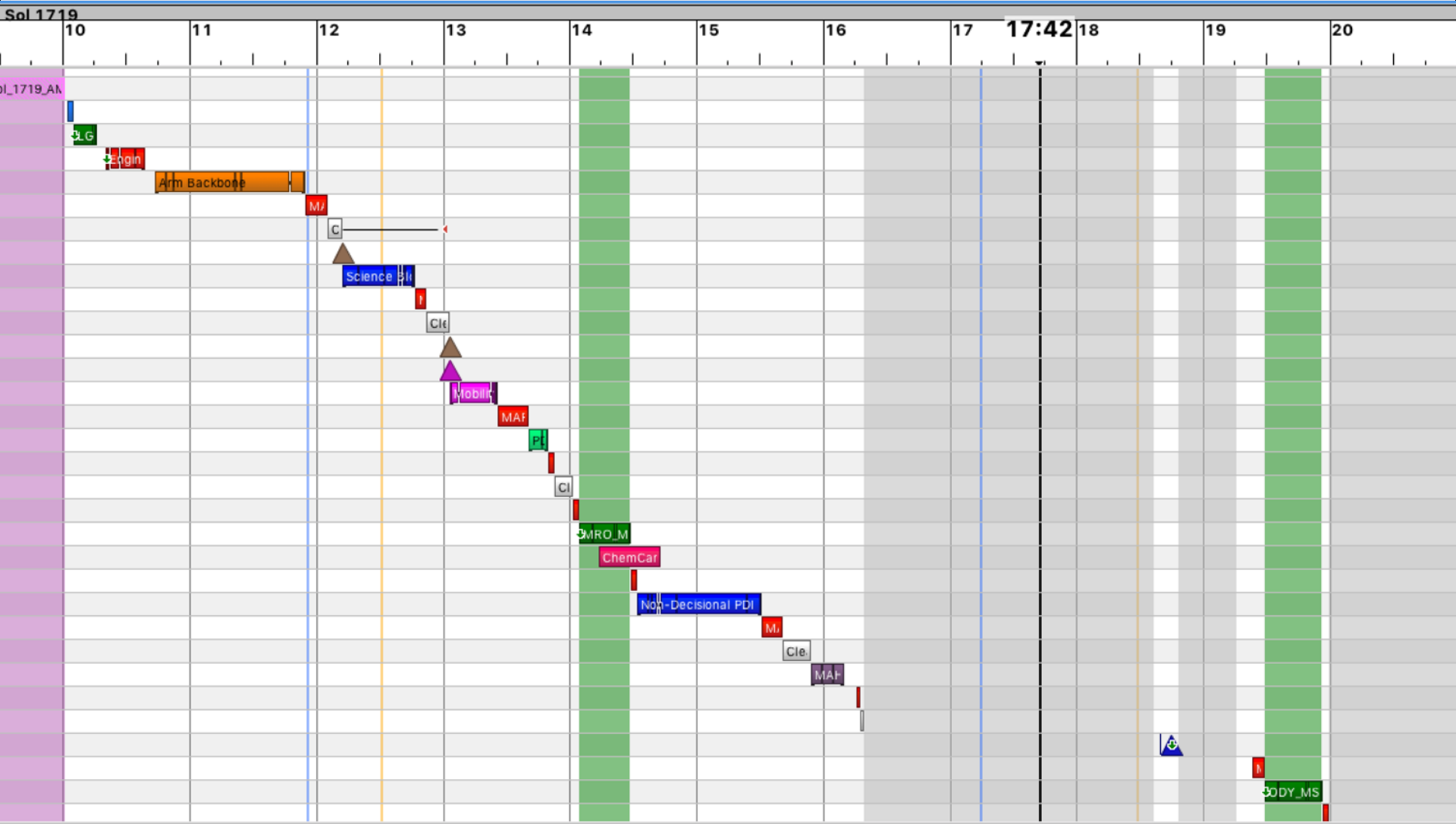


Iteratively inchworm closer for highest accuracy

On M2020 we would like to do the same without ground in the loop

Curiosity planning

A (simplified) typical day on Mars



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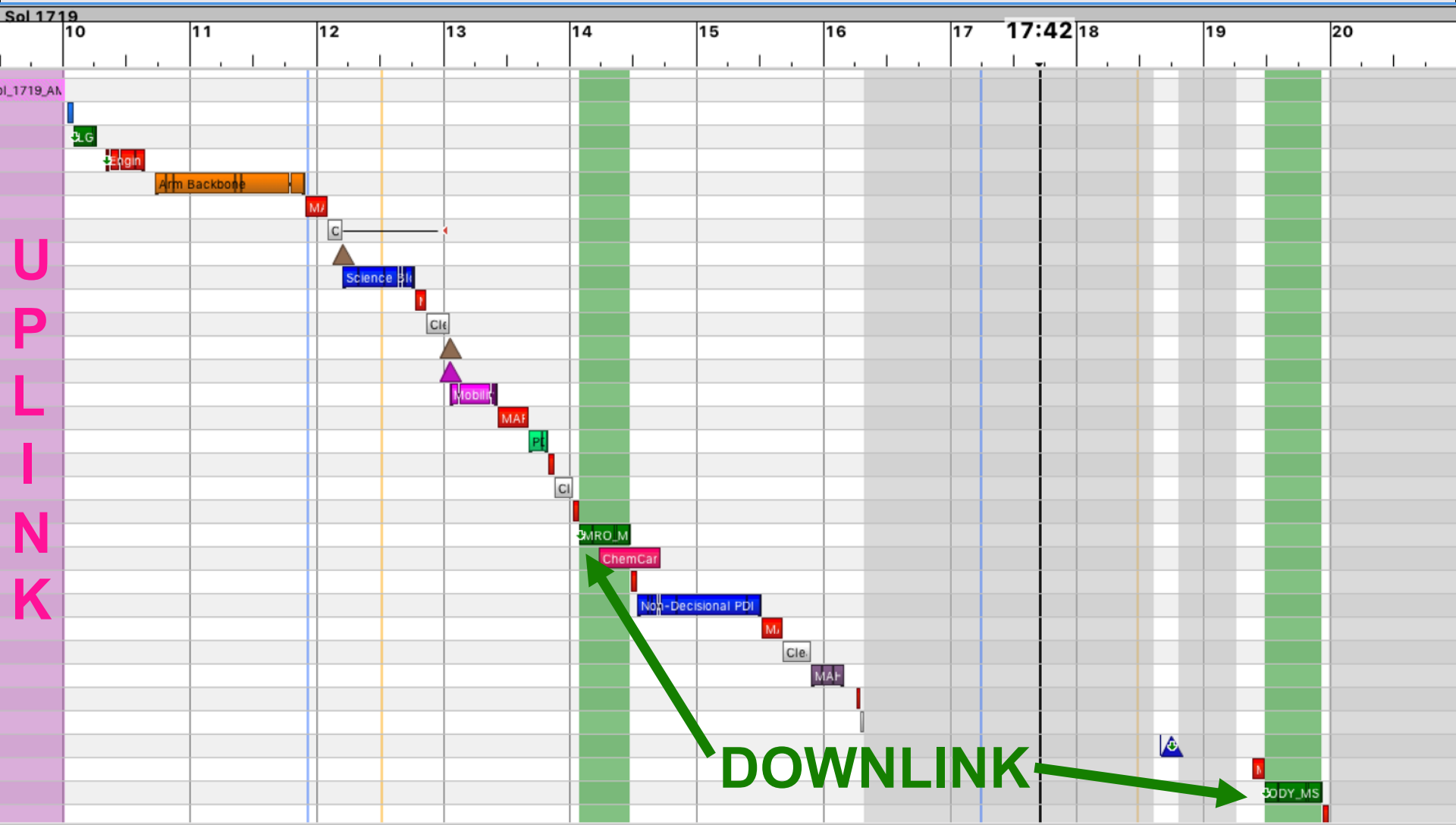

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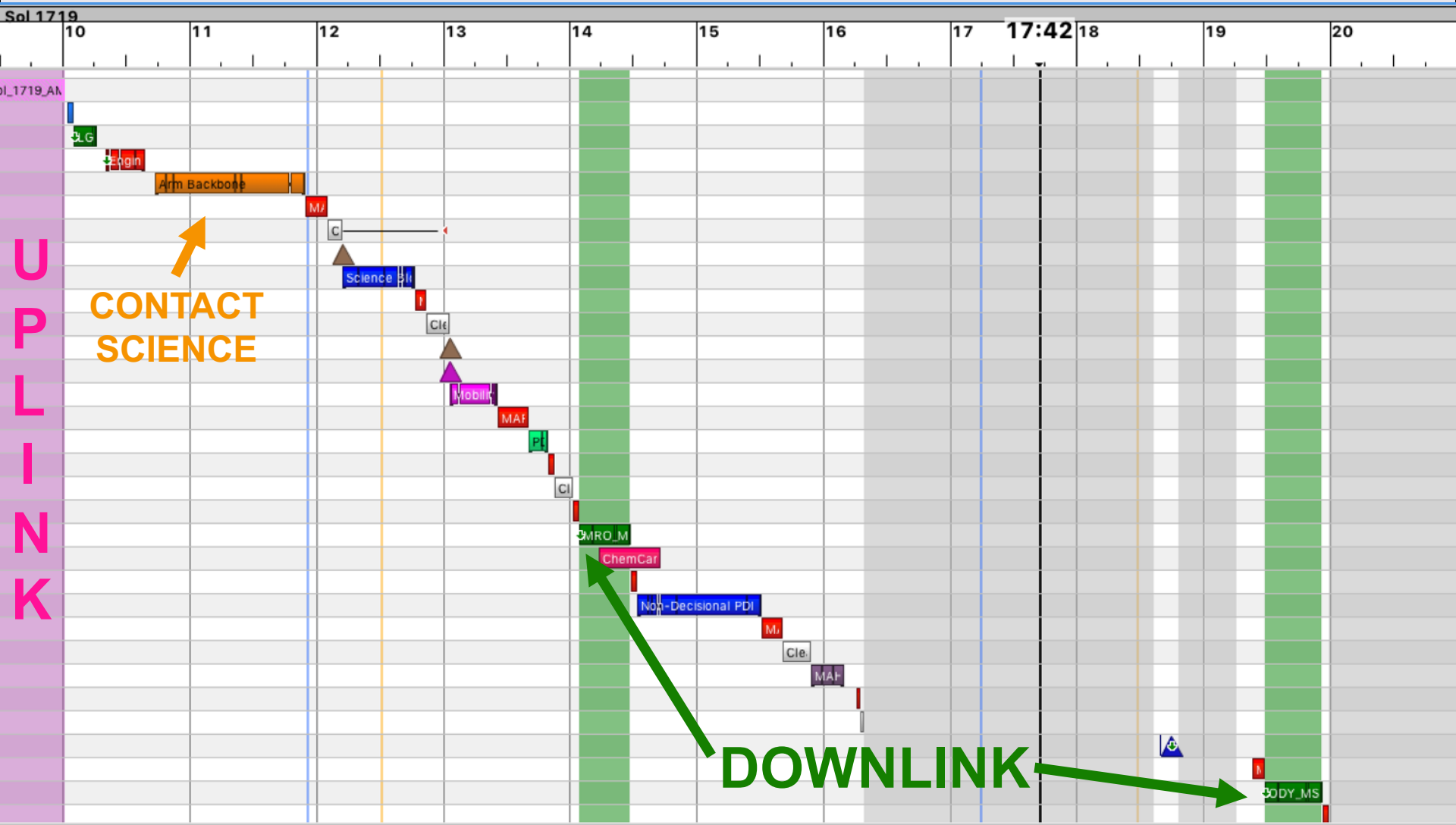

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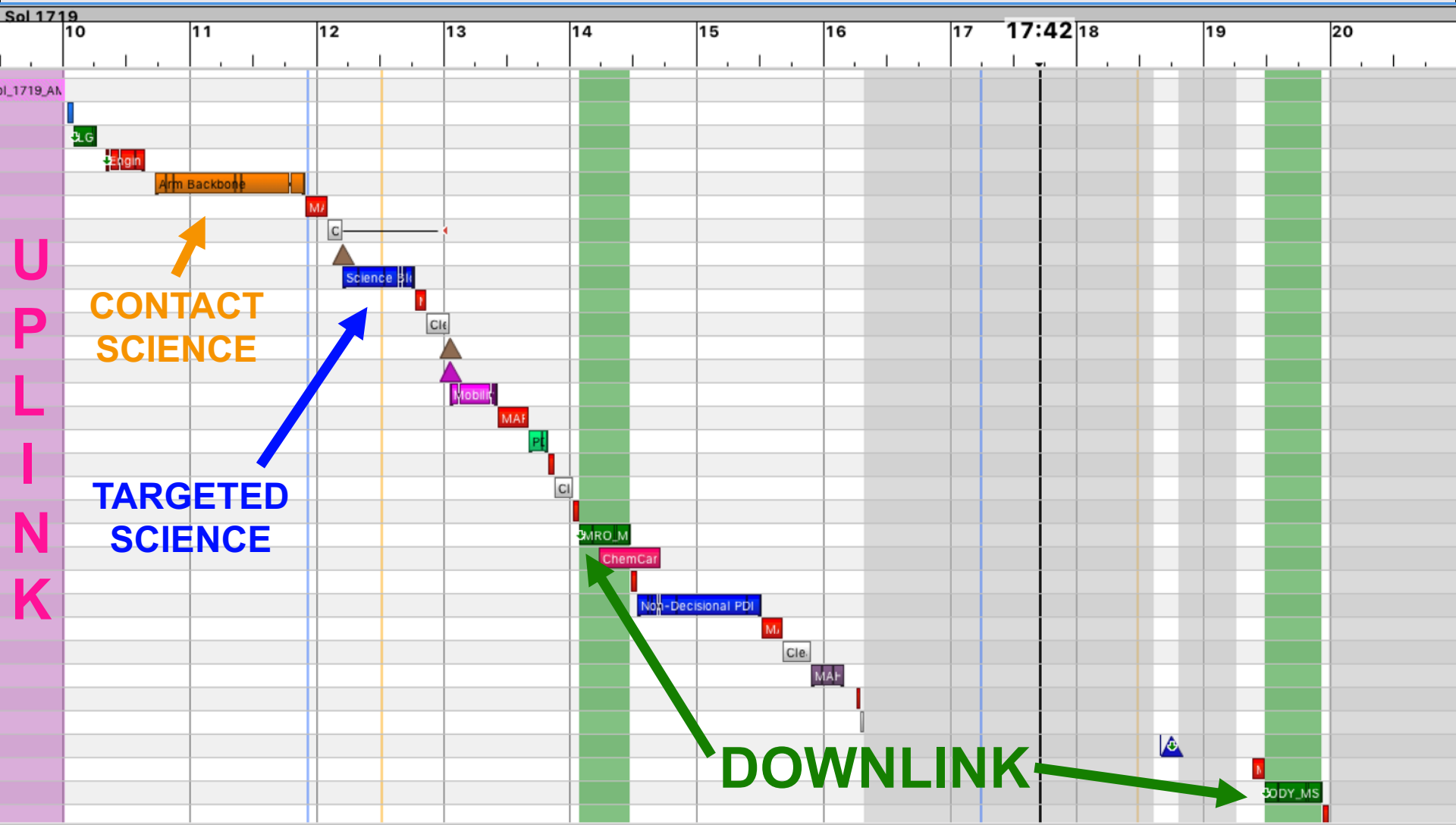

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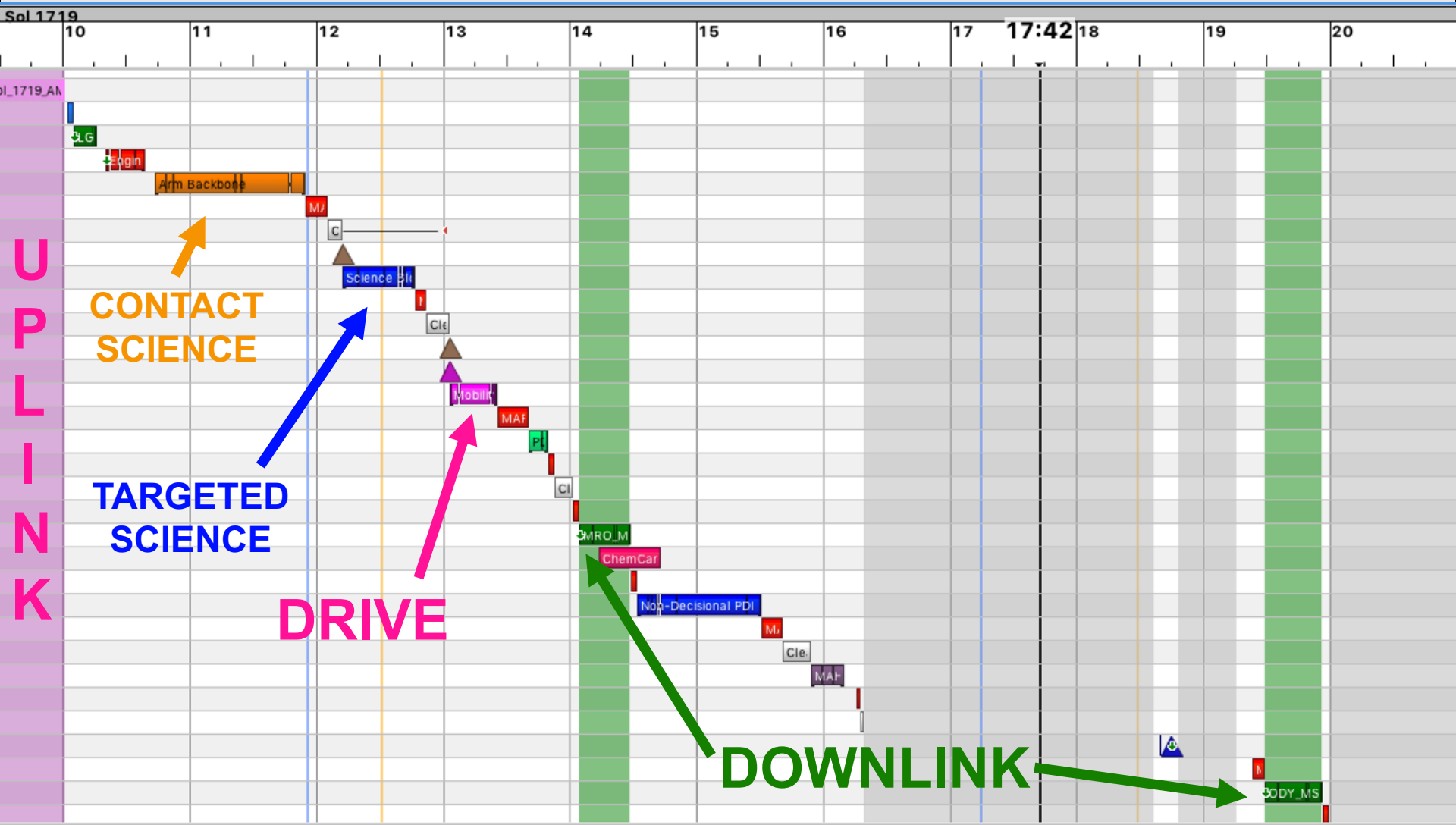

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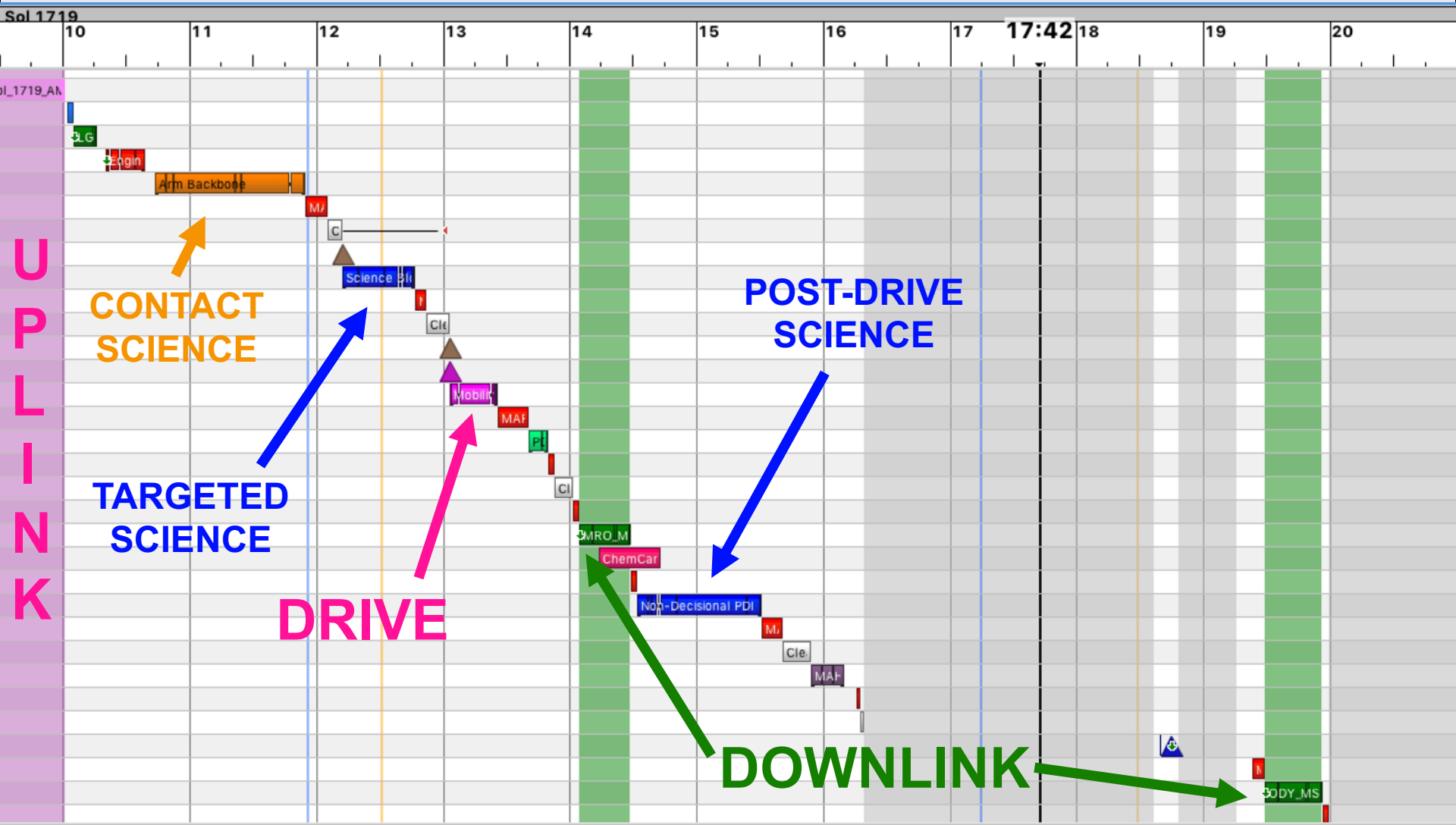
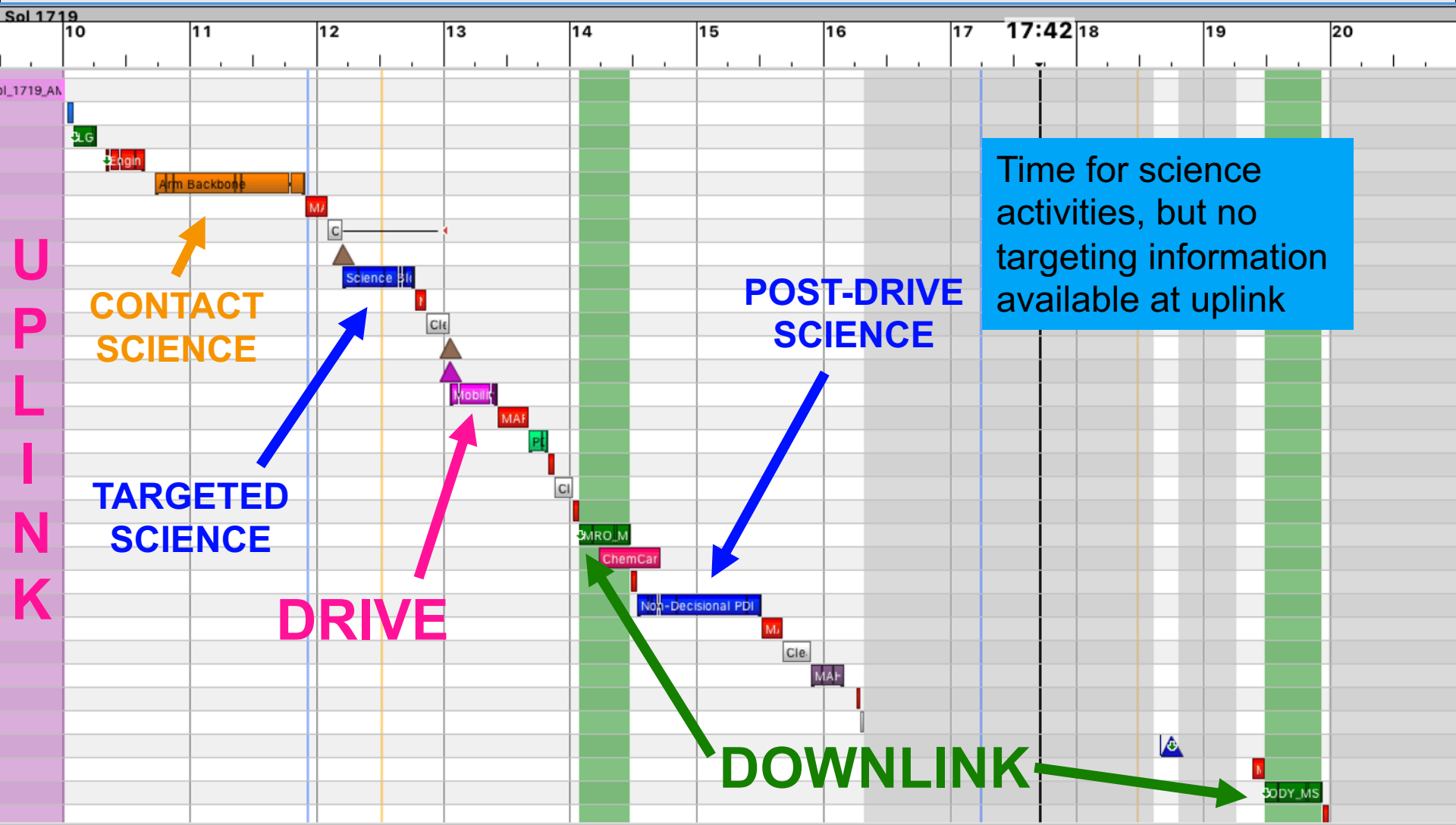


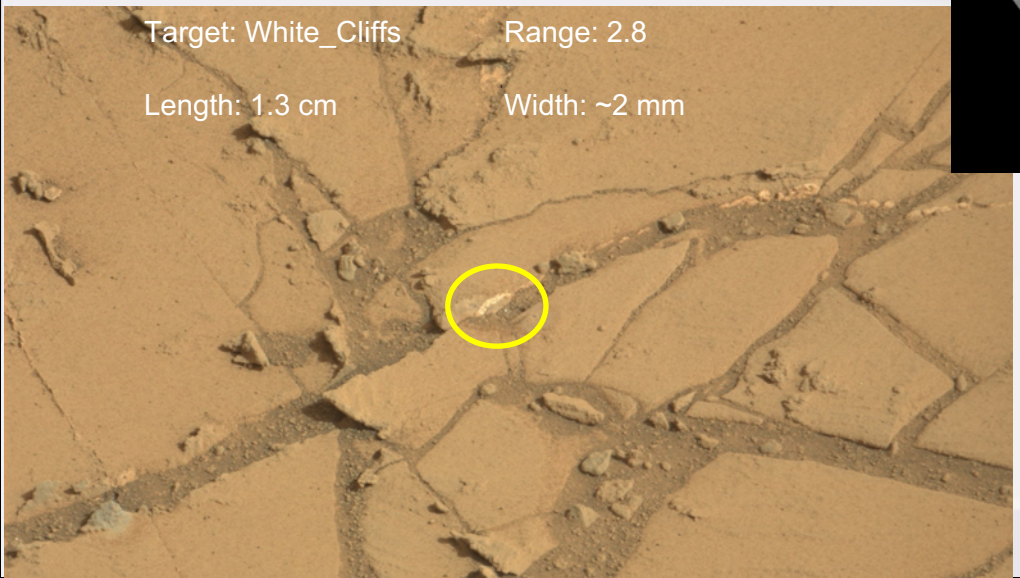
Curiosity planning

A (simplified) typical day on Mars



Pointing challenges

- Pointing precision is a challenge!
  - Backlash
  - Stereo accuracy & registration
  - Rover shifting/settling
  - Thermal expansion
- Missing targets
  - Try again or lose the target



Initial ChemCam raster
1.4 mrad spacing

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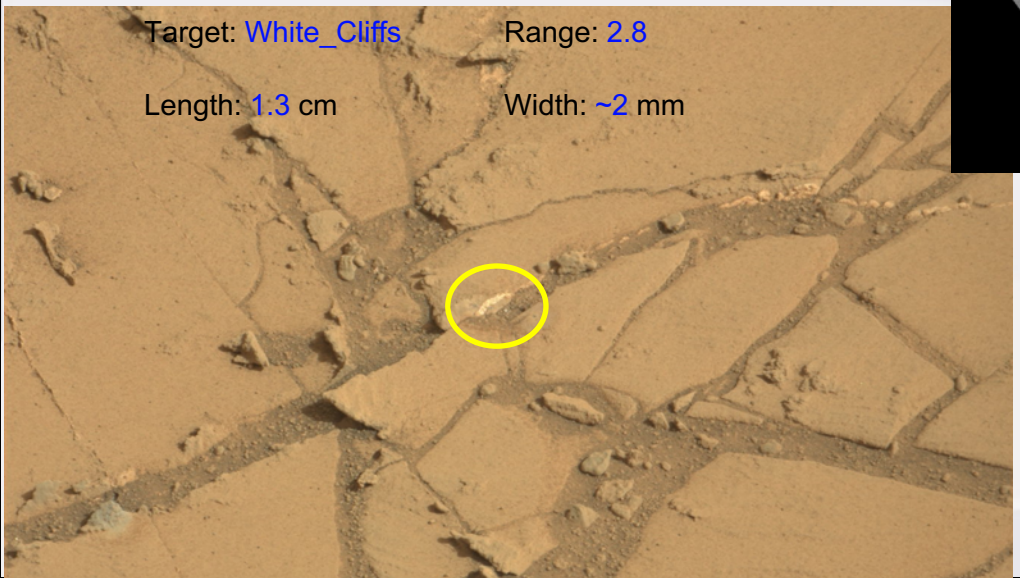
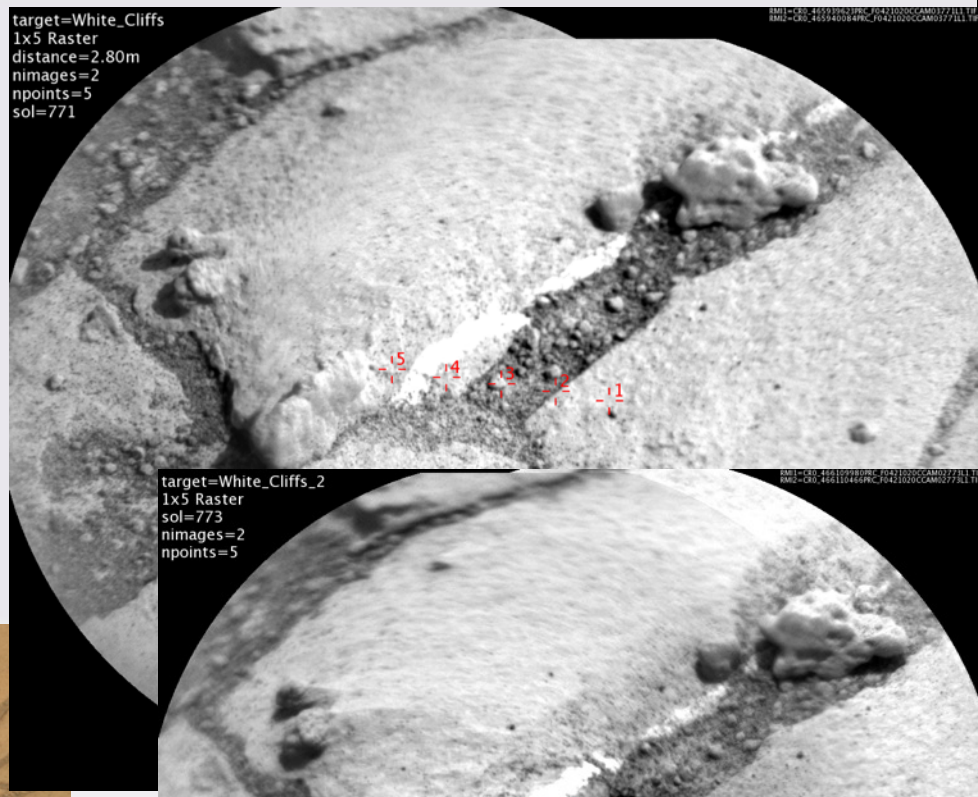




AEGIS Intelligent Targeting System

"Automated Exploration for Gathering Increased Science"

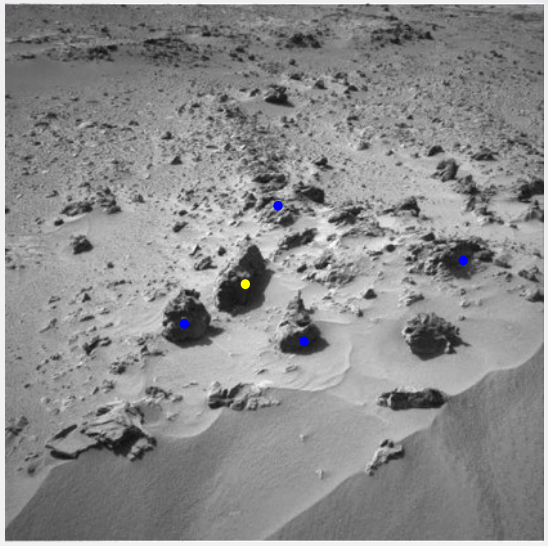
AEGIS was first flown on MER Opportunity in 2010

- Autonomous target selection for PanCam (mid- or post-drive)

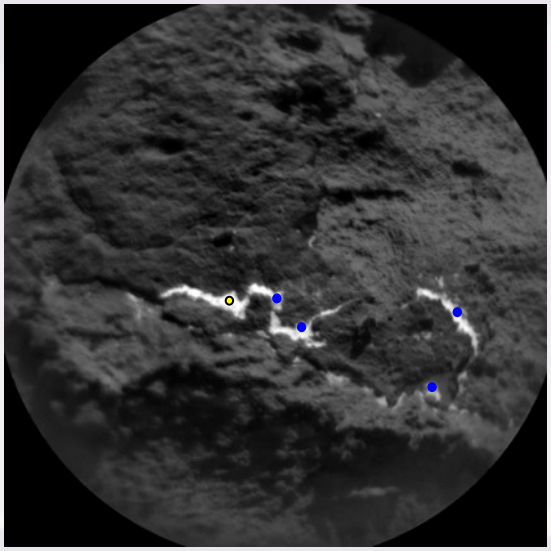
Now in use for ChemCam on Curiosity, in two roles

- Autonomous target selection in NavCam images
- Autonomous pointing refinement in RMI images

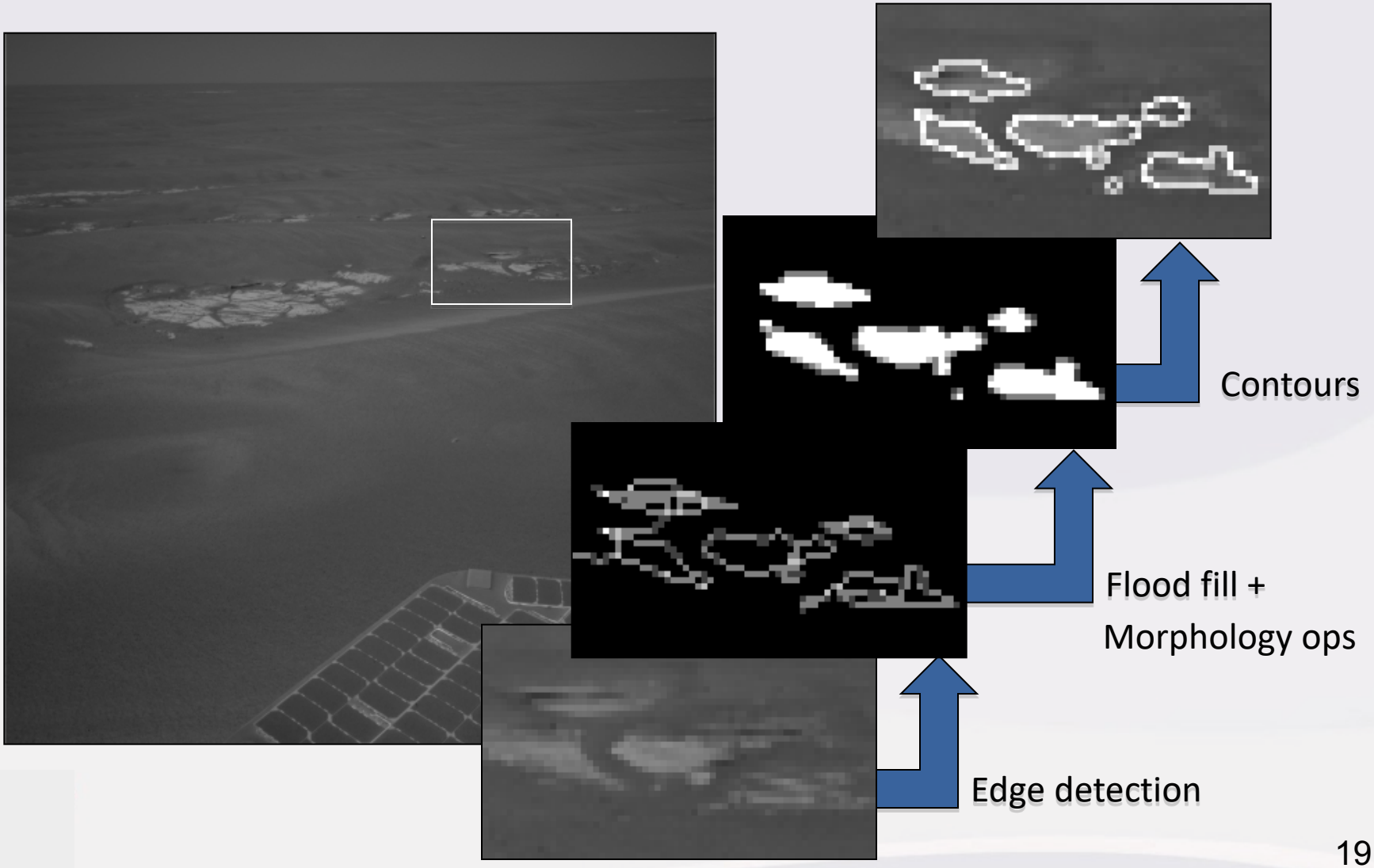
NavCam



RMI



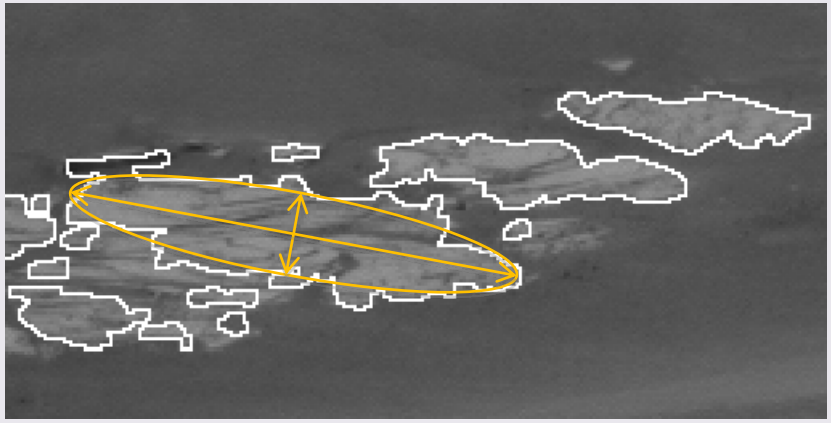
AEGIS Target Detection using Rockster



Target Property Evaluation

Size

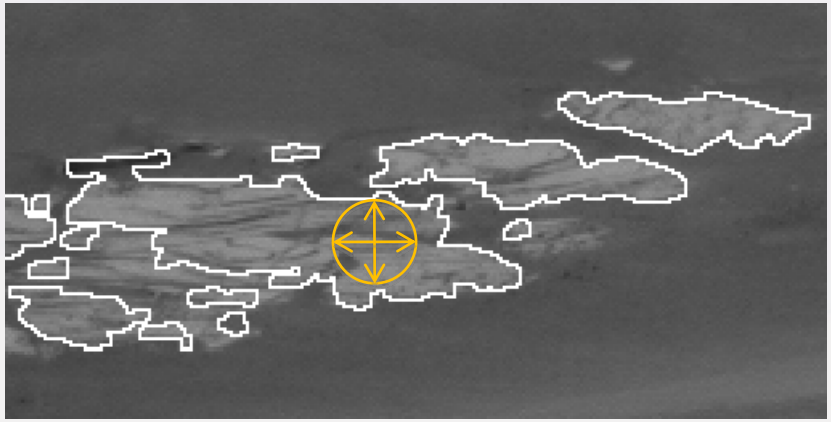
- Number of pixels
- 3D estimate (from stereo)
- Ellipse semi-major axis
- Ellipse semi-minor axis



Ellipse fit example

Position

- Distance from rover
- Inscribed circle x, y
- Site x, y, z
- Site az, el



Inscribed circle example

Target Property Evaluation

Intensity

- Mean
- Variance

Light Dark

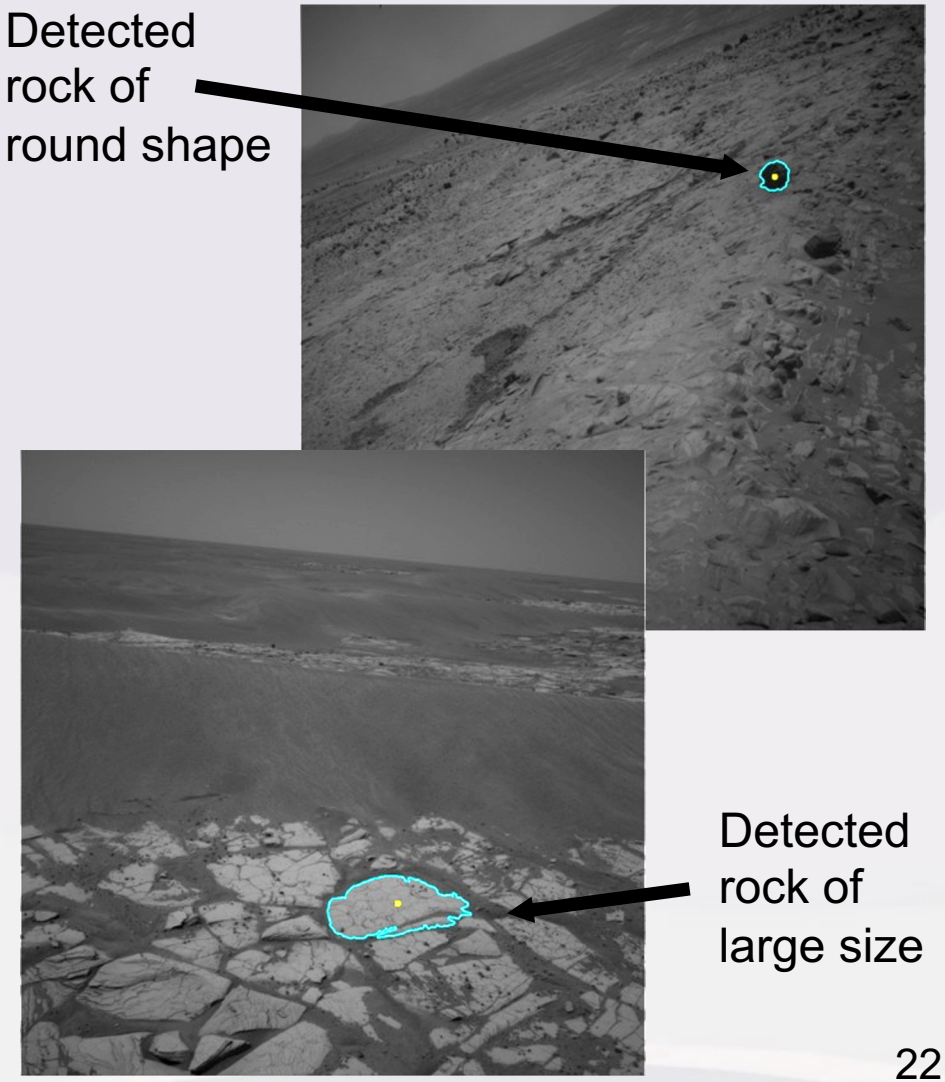
Shape

- Eccentricity
- Ellipse fit error
- Ruggedness
- Orientation

Rounded Angular

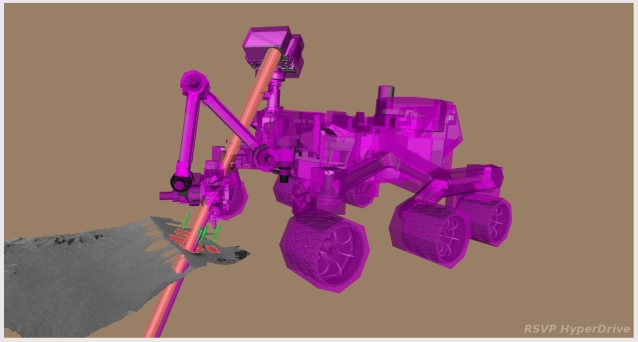
Target Prioritization

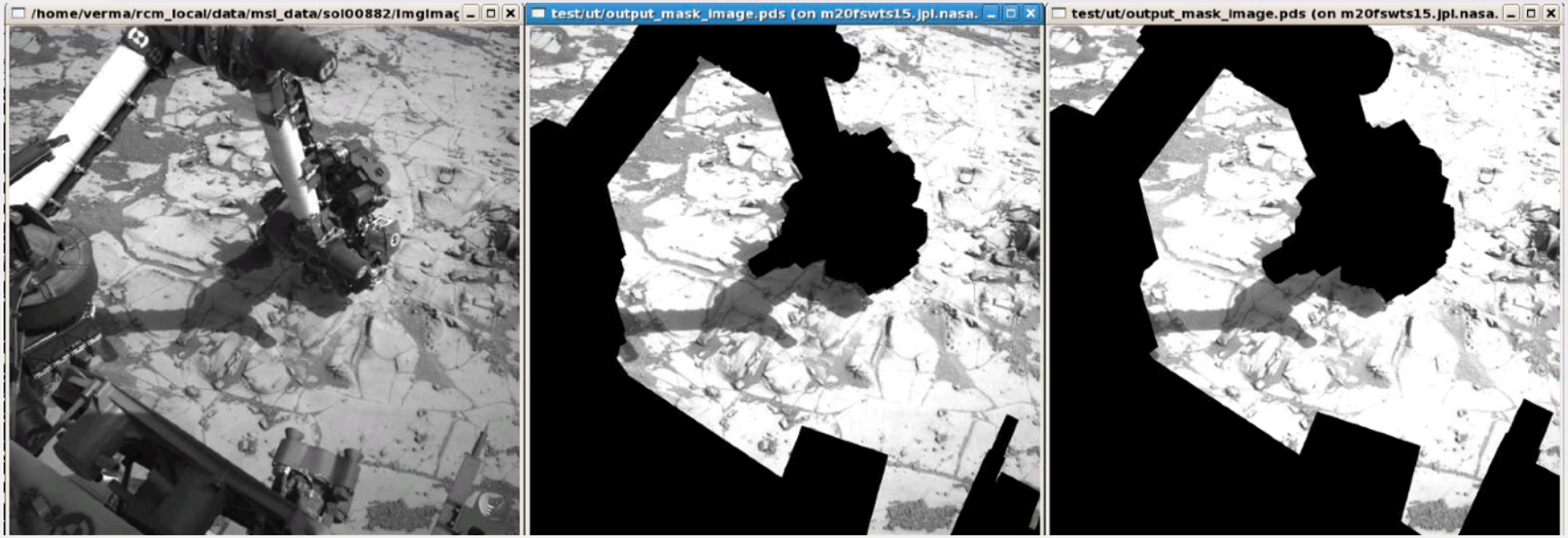
- Scientists can prioritize different property values
  - Single or combinations
  - e.g., prefer large, high albedo rocks
- Property setting is done at command sequencing
- Can be easily changed as rover enters different terrain areas
- Can support specific mission campaigns
  - E.g. cobble finder, outcrop finder



ChemCam Collision Safety

- Don’t shoot the rover!
- AEGIS must recognize and reject unsafe pointings
- Onboard model of rover articulation





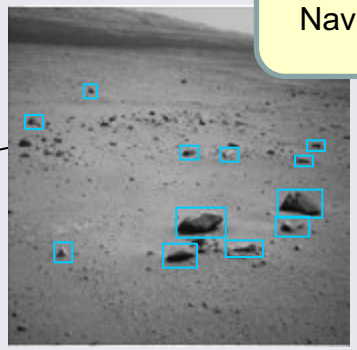
Onboard Process

Image pointing determined by ground.

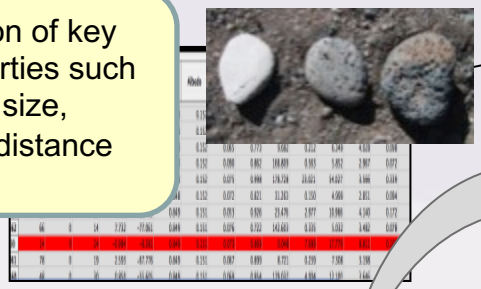
Navcam or RMI acquisition

Target detection

Detection of rock candidates in Navcam image.



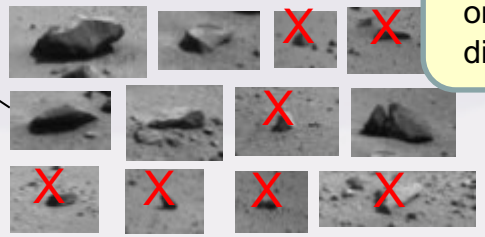
Quantification of key target properties such as intensity, size, shape, and distance from rover.



Target feature extraction

Target filtering

Ops can filter targets based on size, distance, etc.



Ops can prioritize important properties for each run

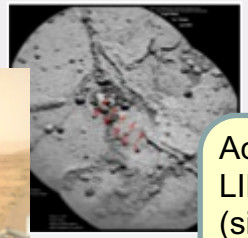
Top score for large size

Target prioritization

Set VTT frame to target position

Can repeat for multiple targets

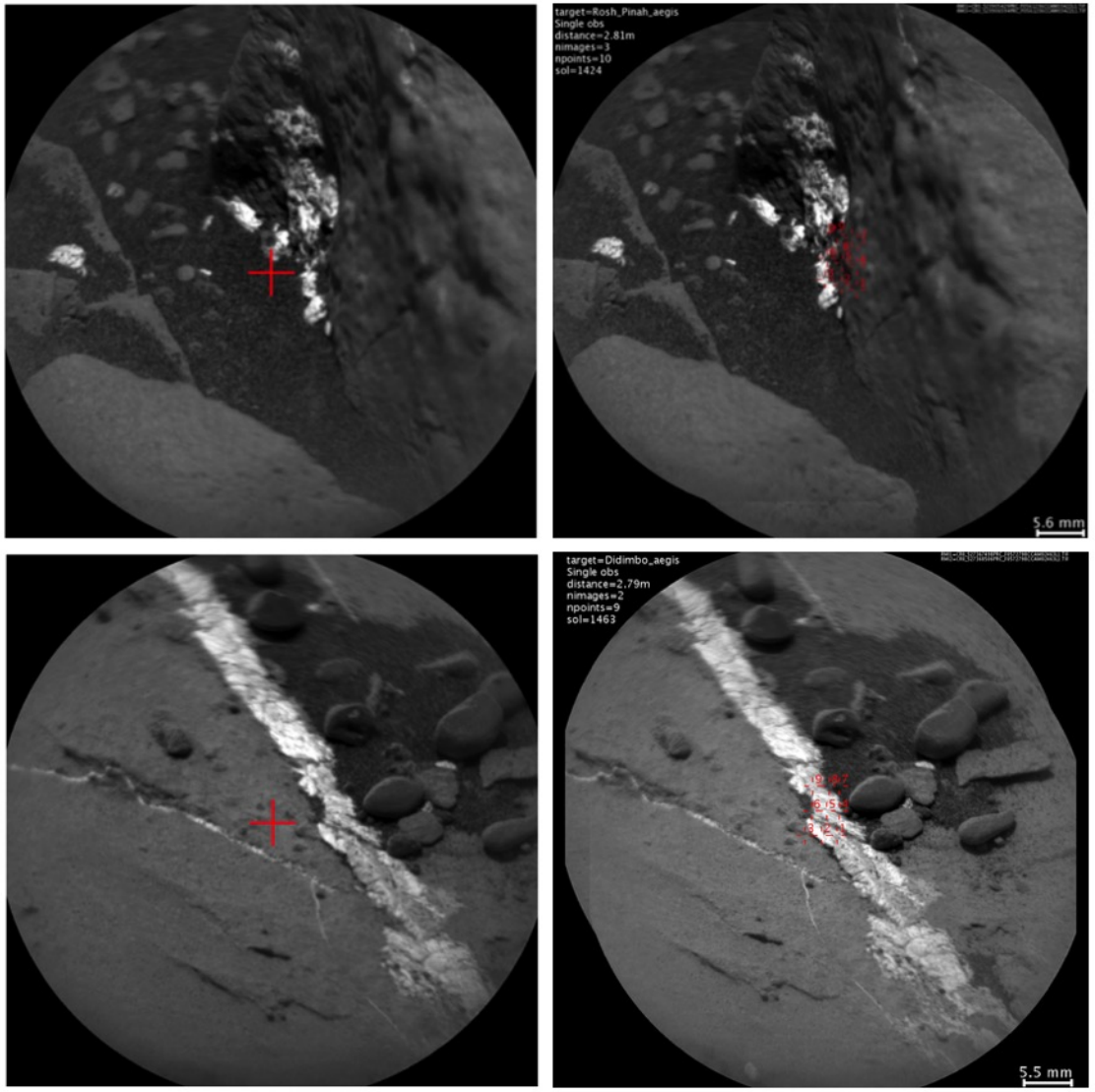
CCAM raster acquired using VTT frame



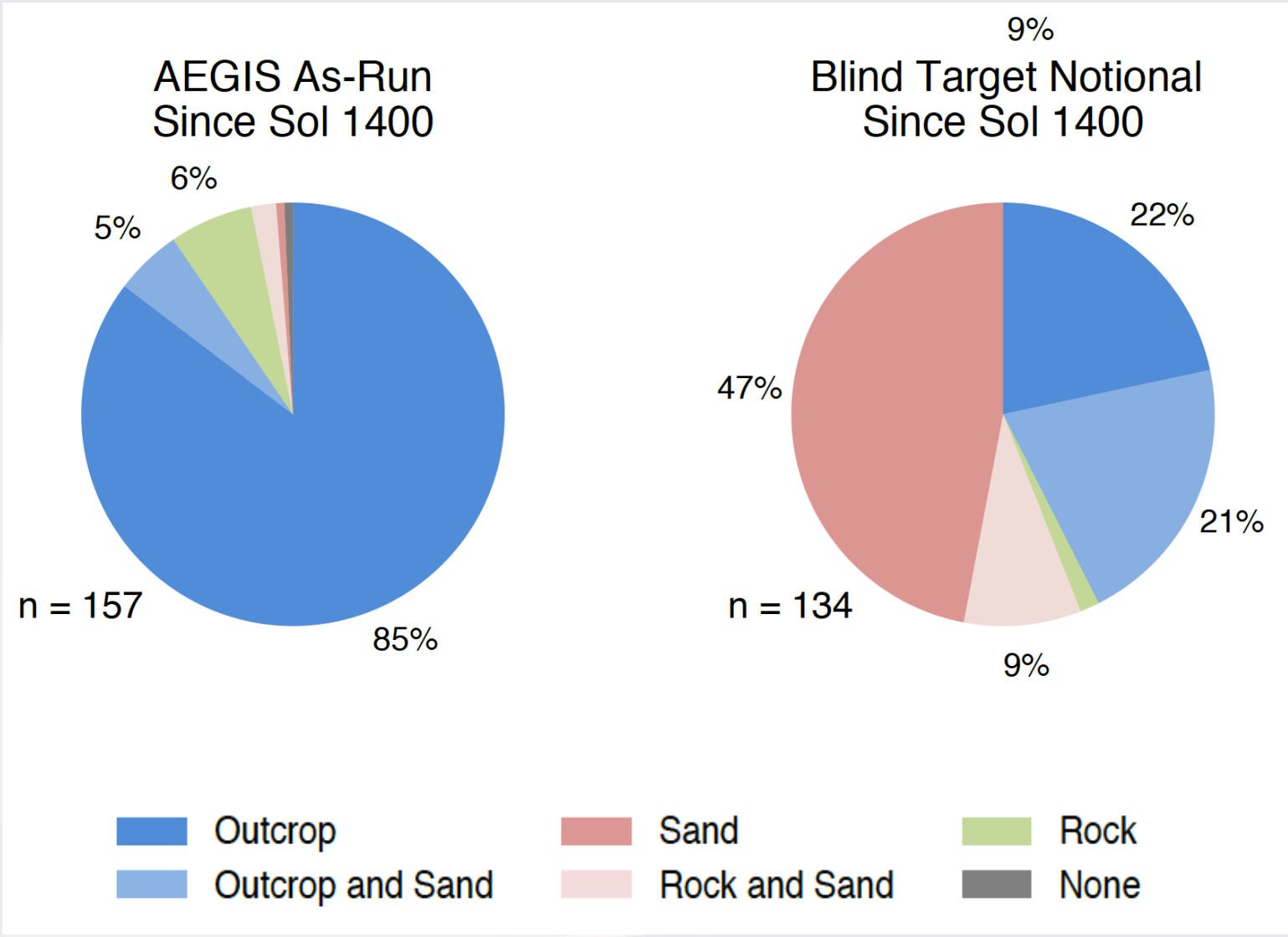
Acquire ChemCam LIBS raster of target (size and direction pre-specified by ground)

Results: Pointing refinement

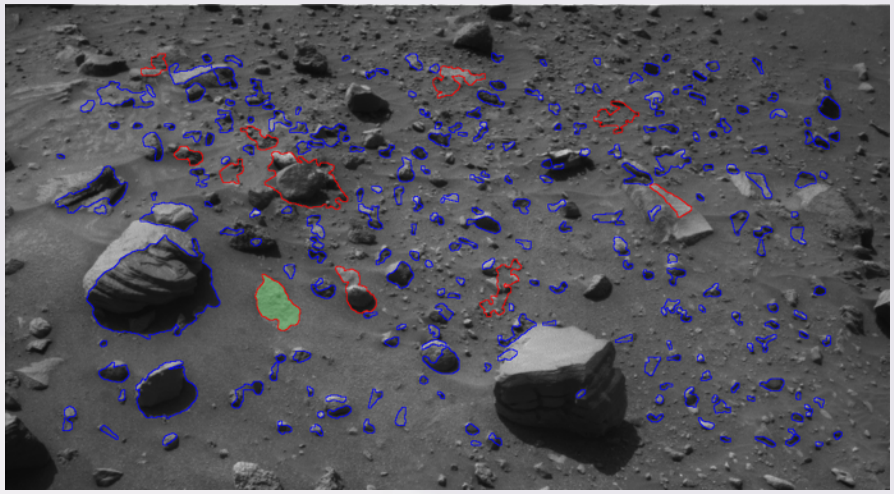
- Sol 1424 & Sol 1463
- Small, bright features
  - RMI FOV: 20 mrad Ø
- Initial (ground-selected) pointing missed target
- AEGIS corrected pointing and hit the target
- Saved observation – a manual retargeting second attempt would have been necessary. Not possible if rover were to drive in that plan



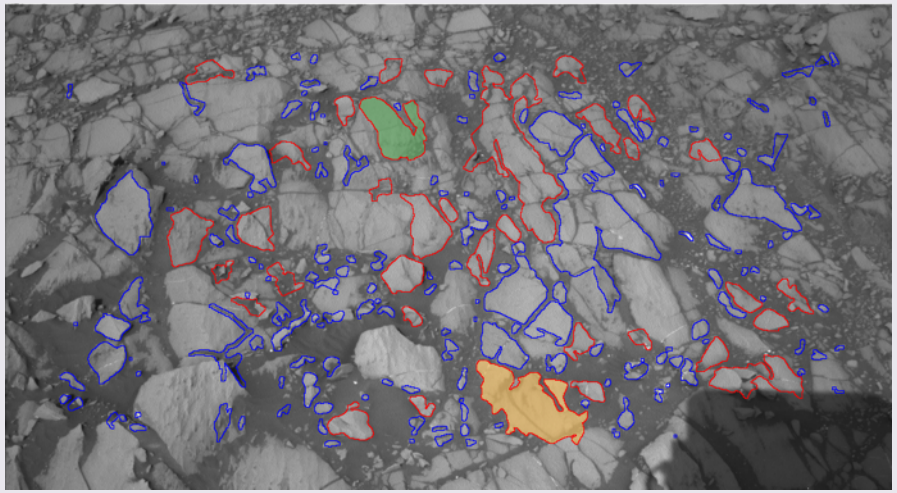
Results: Target selection



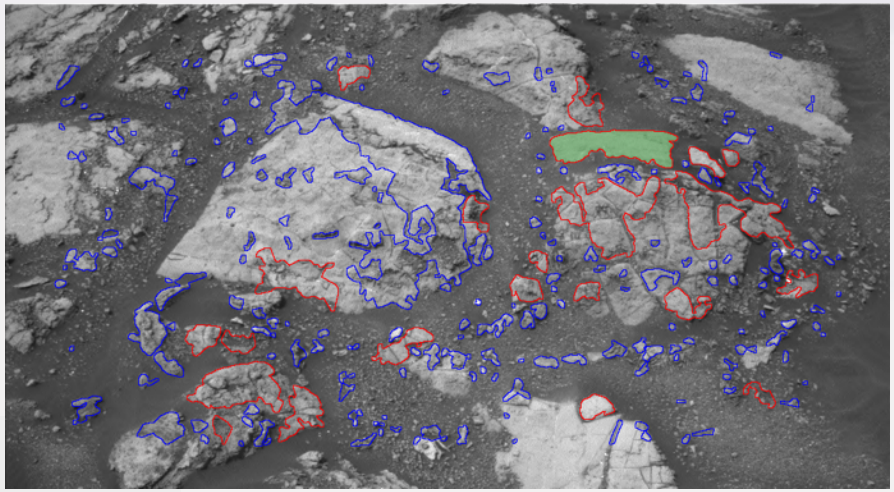
Results: Target selection



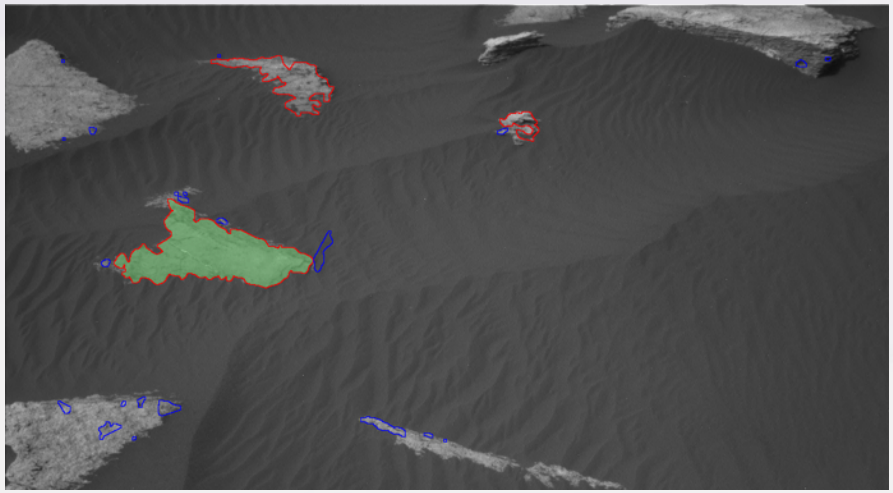
Sol 1400



Sol 1417

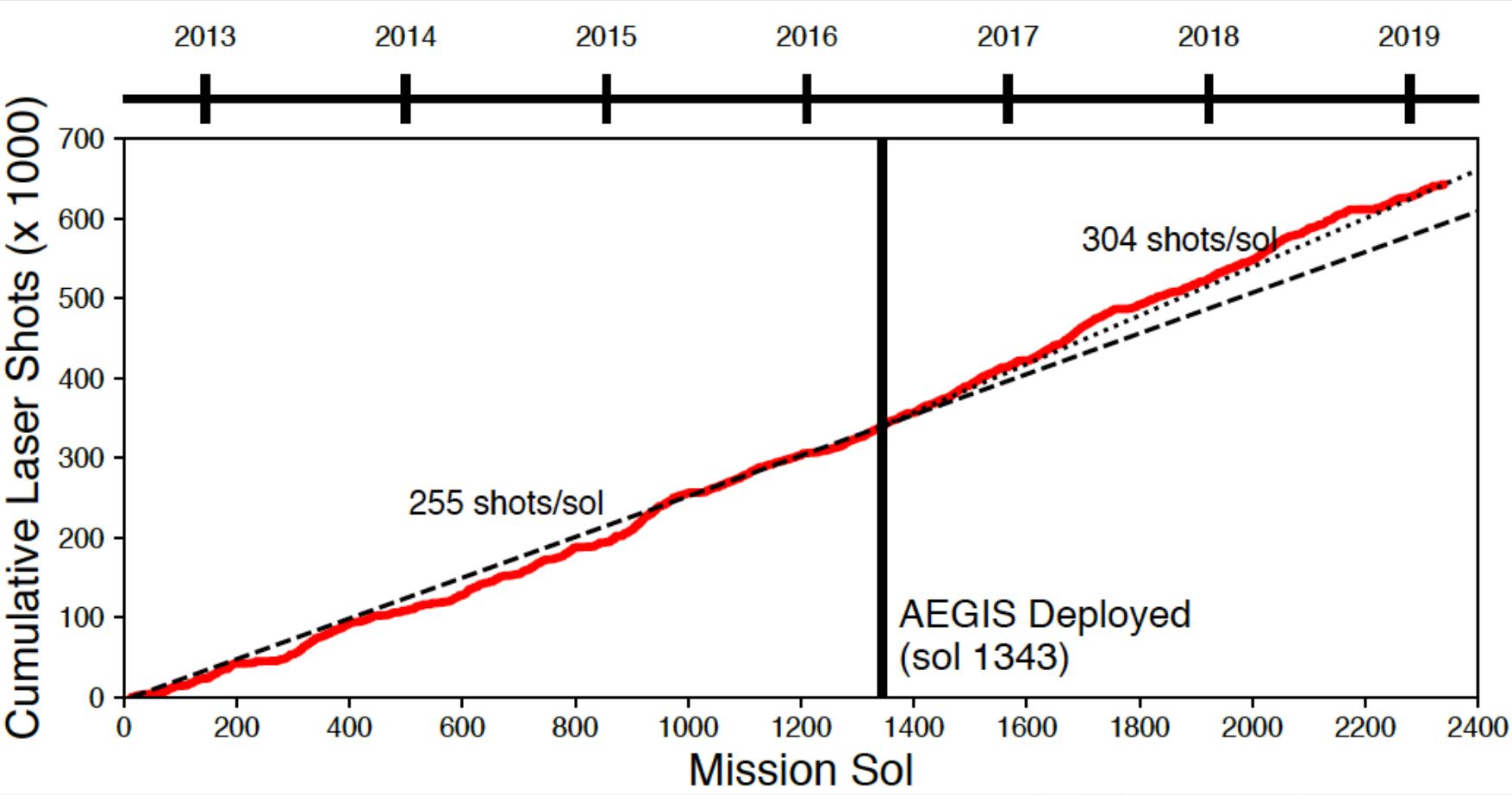


Sol 1481



Sol 1636

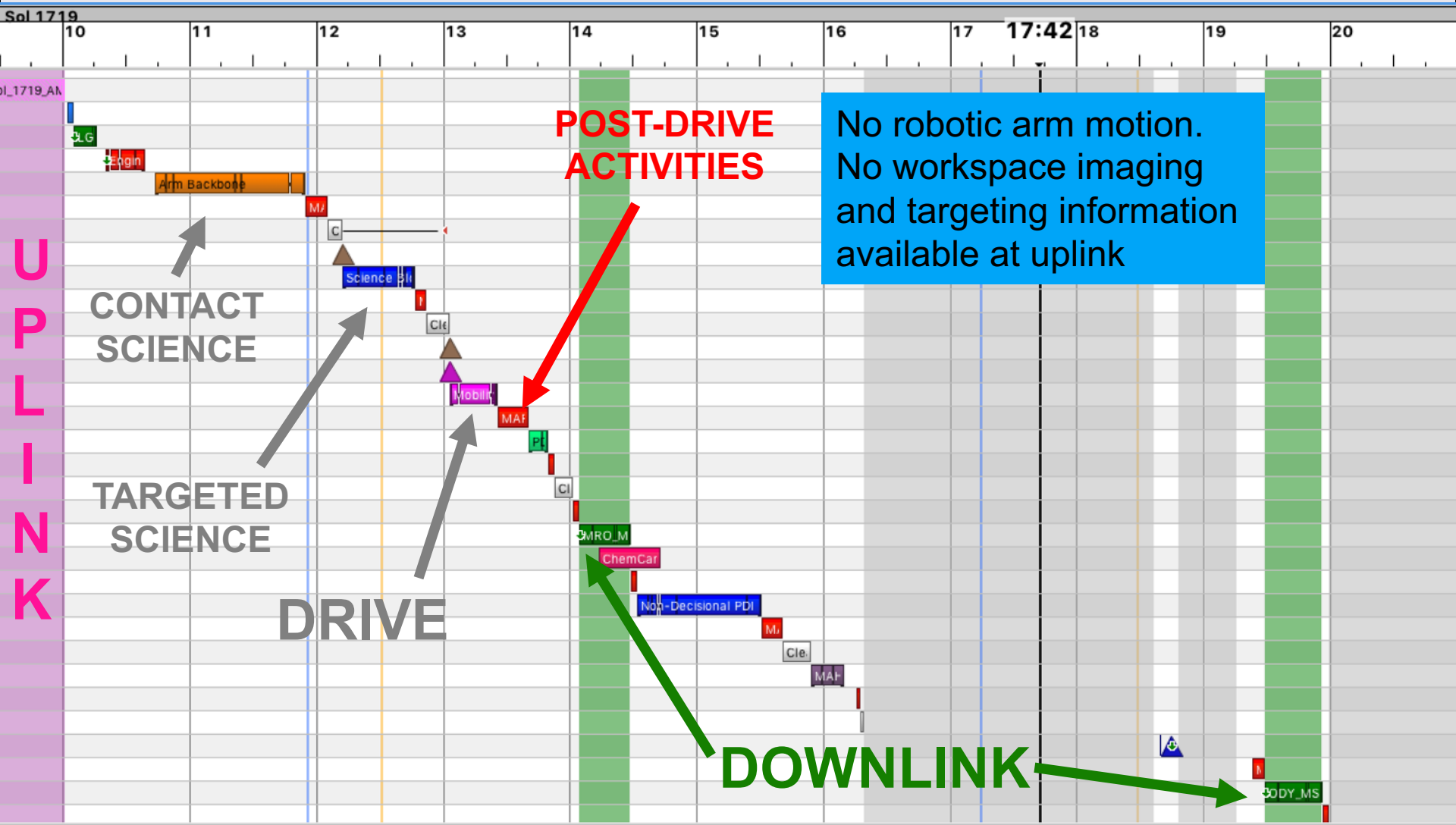
More data from ChemCam



- Significant increase in rate of data return from ChemCam
- AEGIS rollout to science team on sol 1343

Mars 2020 planning

A (simplified) typical day on Mars



Terrain Height Map

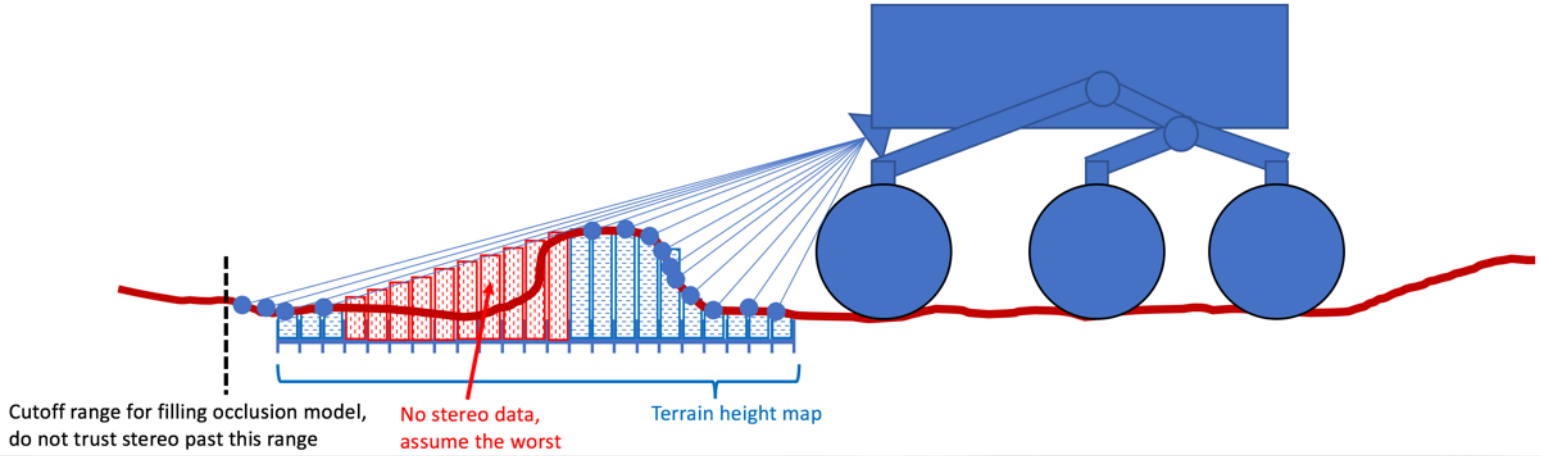
Fine resolution terrain map
256x256 cells, mapping 2.0x2.0 m

4. Then, build medium resolution map from max Z of cells in the fine resolution height/occlusion map

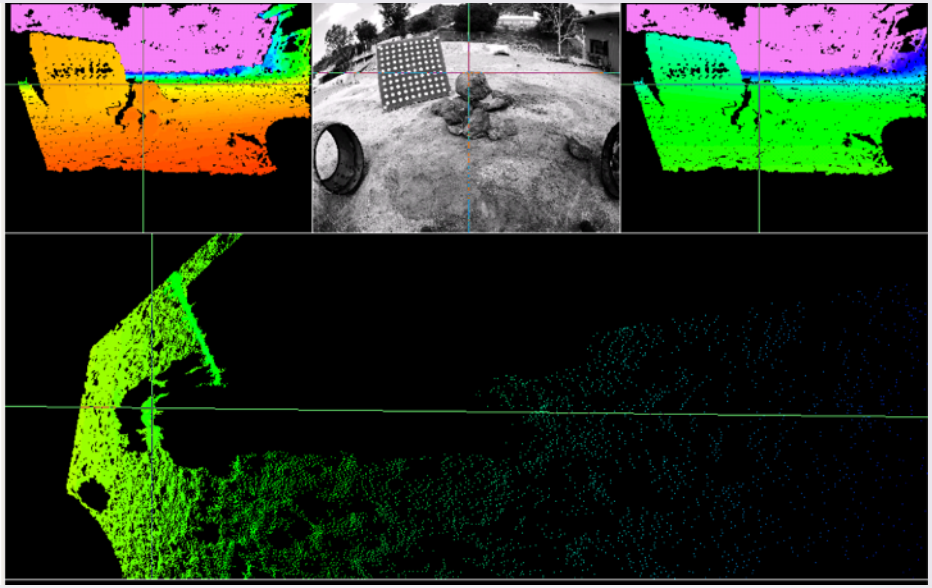
Medium resolution terrain map
16x16 cells, mapping 2.0x2.0 m

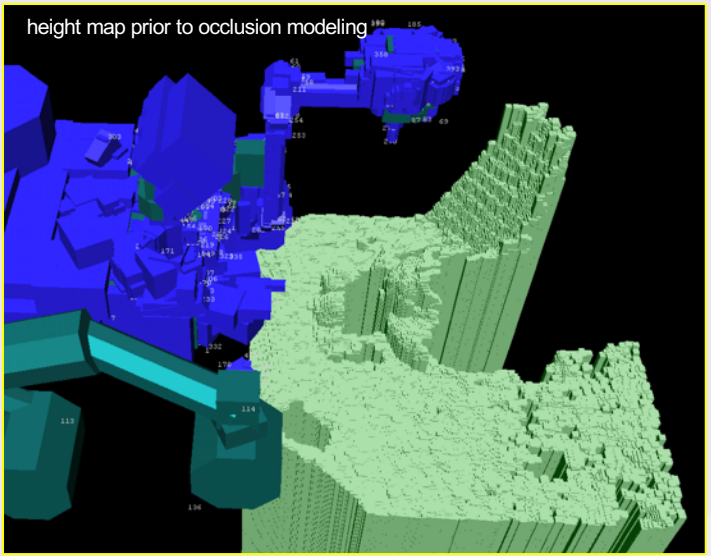
5. Finally, repeat to build coarse resolution map

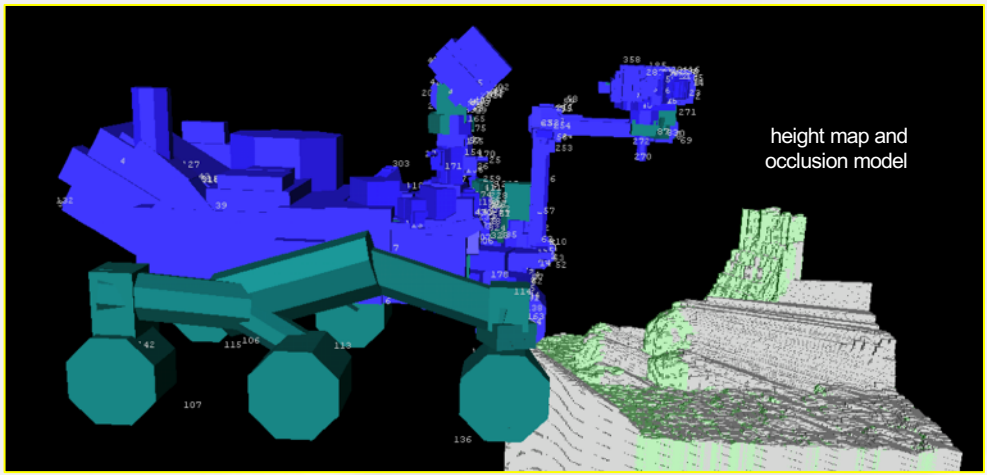
Coarse resolution terrain map
2x2 cells, mapping 2.0x2.0 m



Mars Yard Test Cases







Flight Infusion Challenges

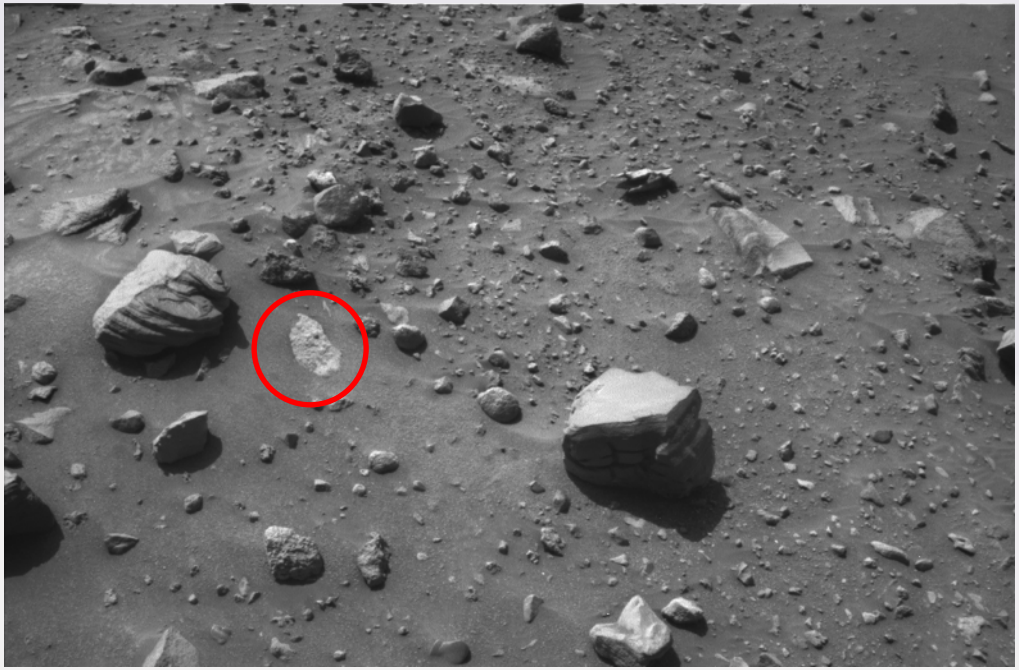
- 133 MHz RAD750 flight processor
- Limited onboard memory
  - 256 MB of DRAM, 128 MB of RAM
    - AEGIS limited to 16MB
    - Autonomous arm positioning limited to 16MB
- Safety constraints
  - Sun-Safety
  - Collision
- Operations complexity
  - New commands need to be intuitive for operators to use
  - Must add operational value over traditional commanding

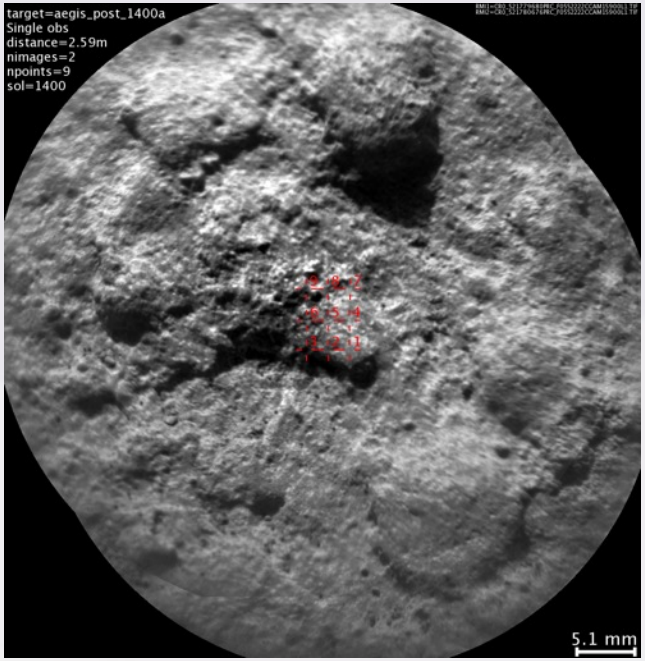
Autonomous Target Selection and Observation for Curiosity and Mars 2020 Rovers

Vandi Verma
NASA Jet Propulsion Laboratory, California Institute of Technology
vandi@jpl.nasa.gov

Notable events

- **Sol 1400: AEGIS selects the only clear patch of bedrock in the field of view.**





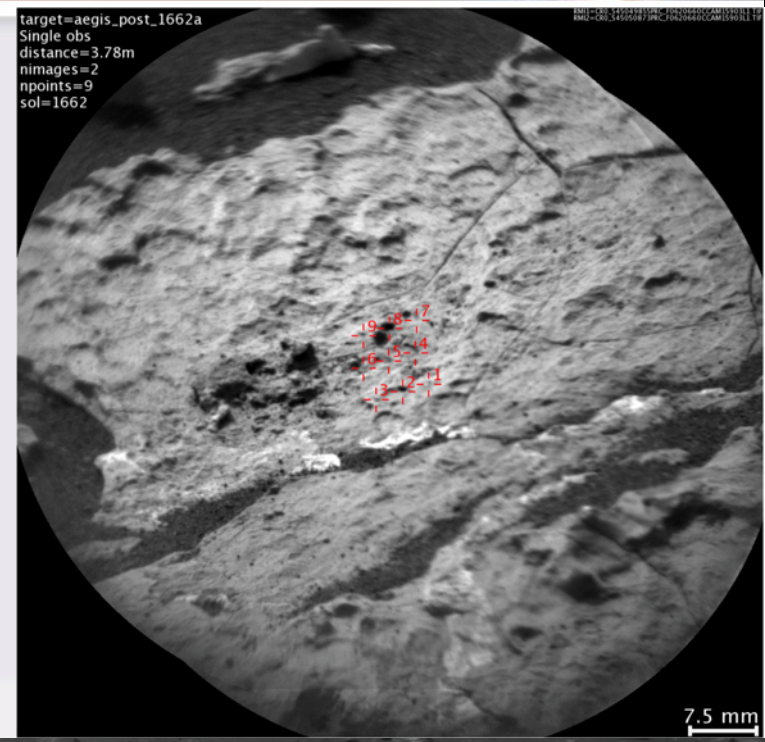
Notable events

Sol 1662: Finding unusual chemistry

Rock was visually unremarkable

Points 5 & 8 had notable chemistry for the local bedrock, with certain elemental abundances unusual

Team spent a targeted observation revisiting this spot.

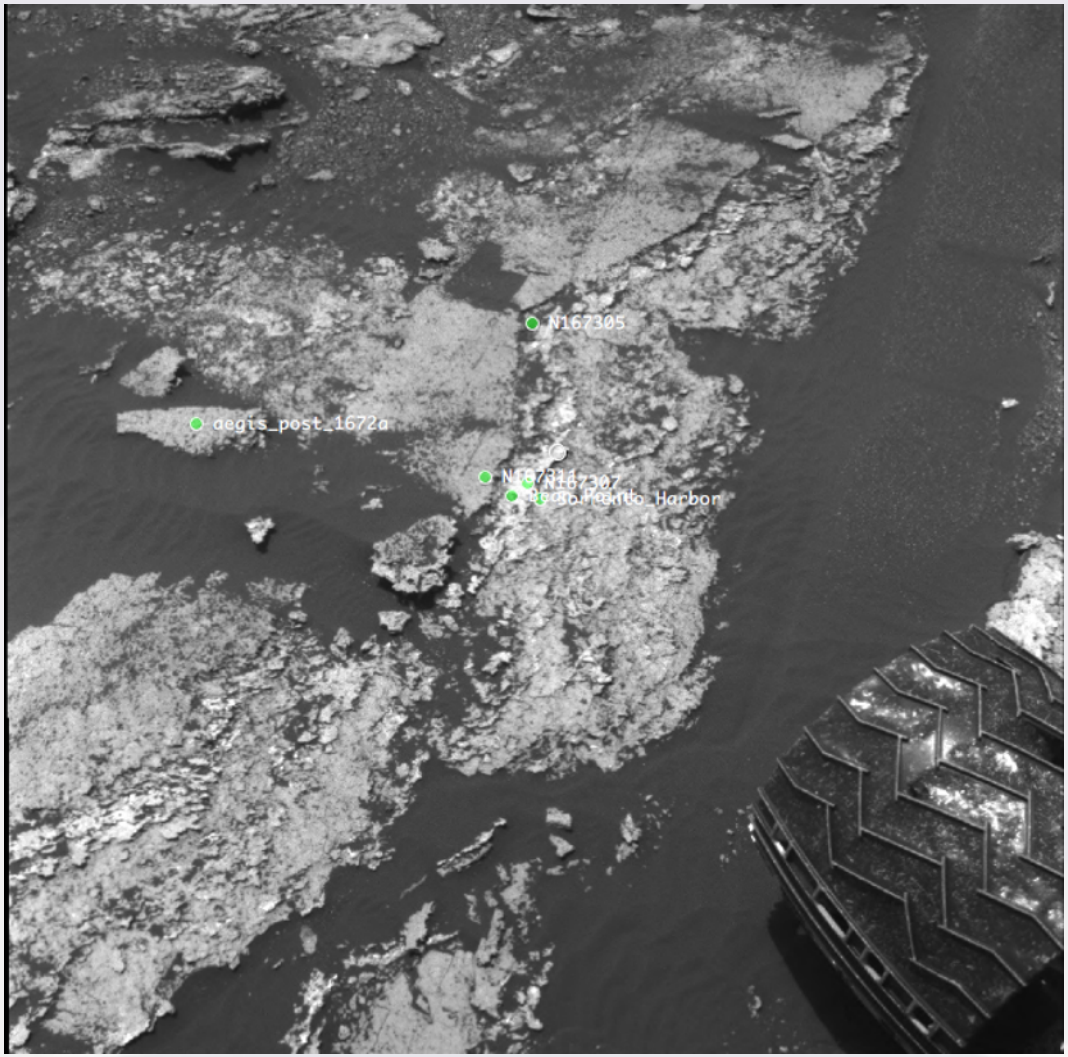


Notable events

Sol 1673: Collect all 3

Upper, smooth material
Brighter vein
Lower, rough material

AEGIS had already measured the upper unit, allowing a complete survey with only 2 targeted measurements



Notable events

Sol 1673: Collect all 3

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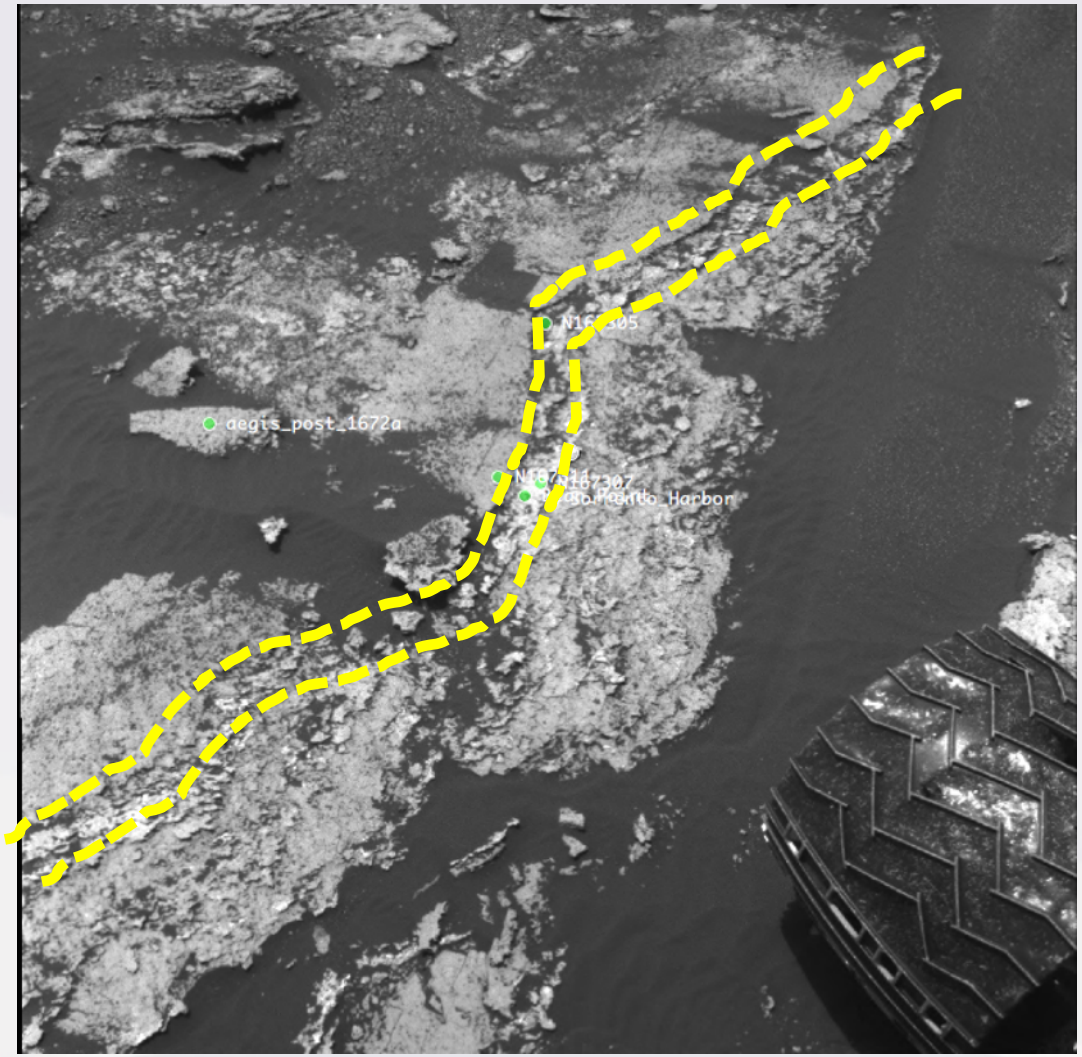
2) Brighter vein
3) Lower, rough material

AEGIS had already measured the upper unit, allowing a complete survey with only 2 targeted measurements

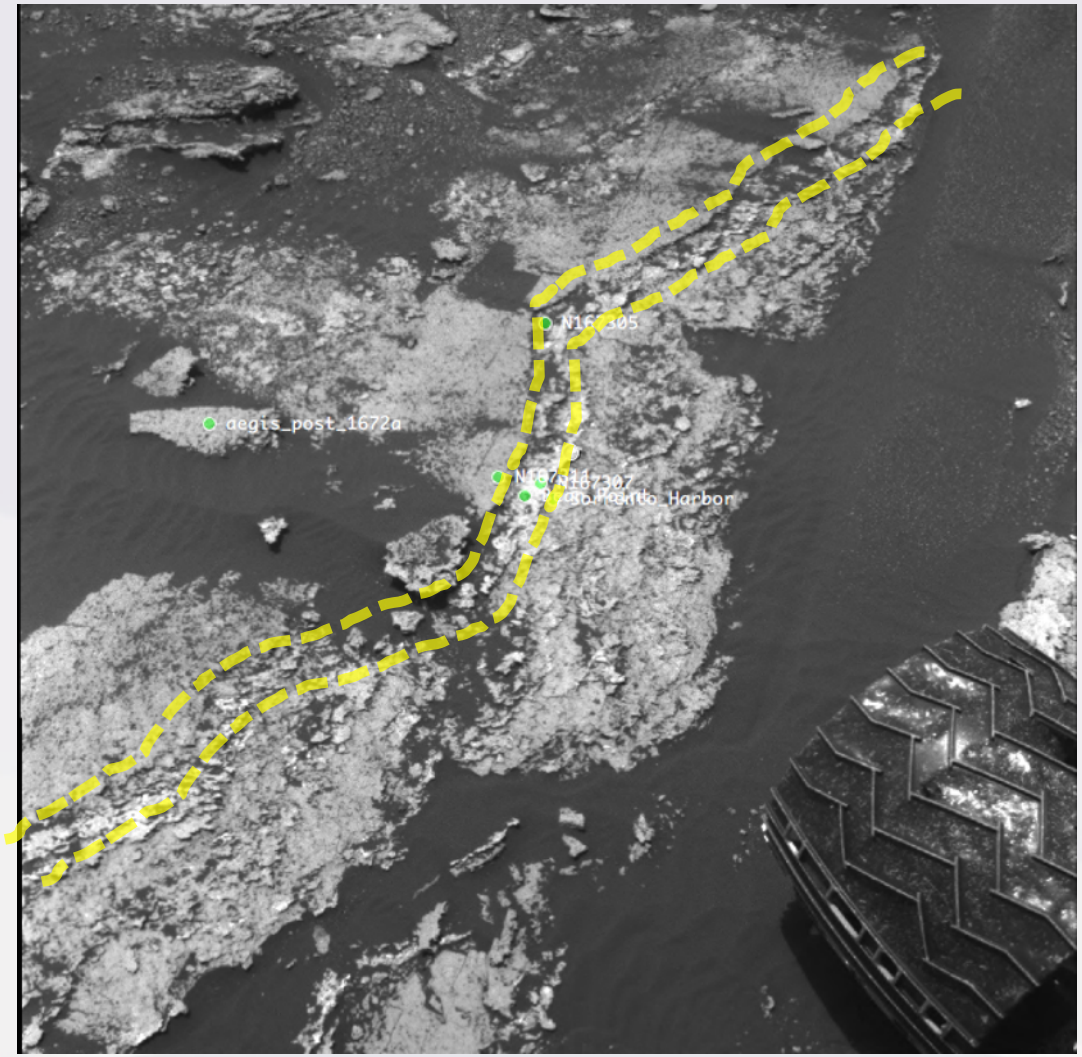


Notable events

Sol 1673: Collect all 3

1) Upper, smooth material
2) Brighter vein
3) Lower, rough material

AEGIS had already measured the upper unit, allowing a complete survey with only 2 targeted measurements



Sol 1612: Highest chlorine

Highest concentration of chlorine ever measured by ChemCam on Mars

(So high it strains the calibration)

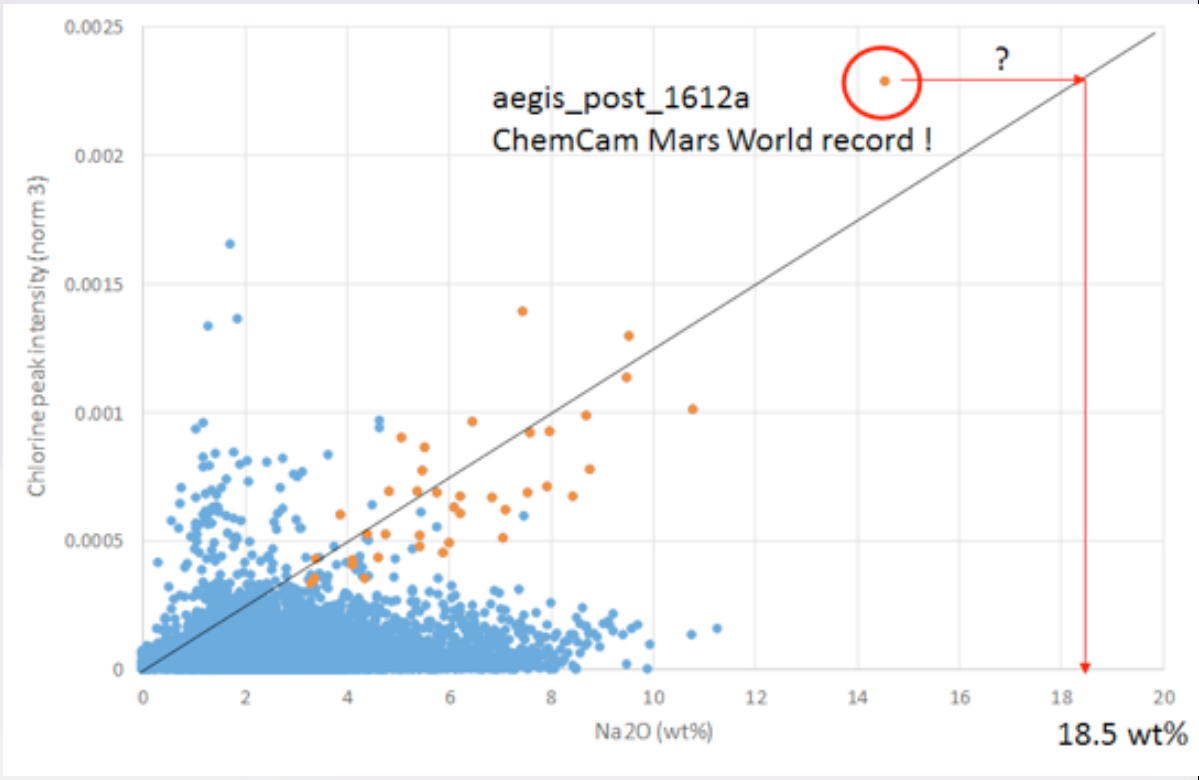
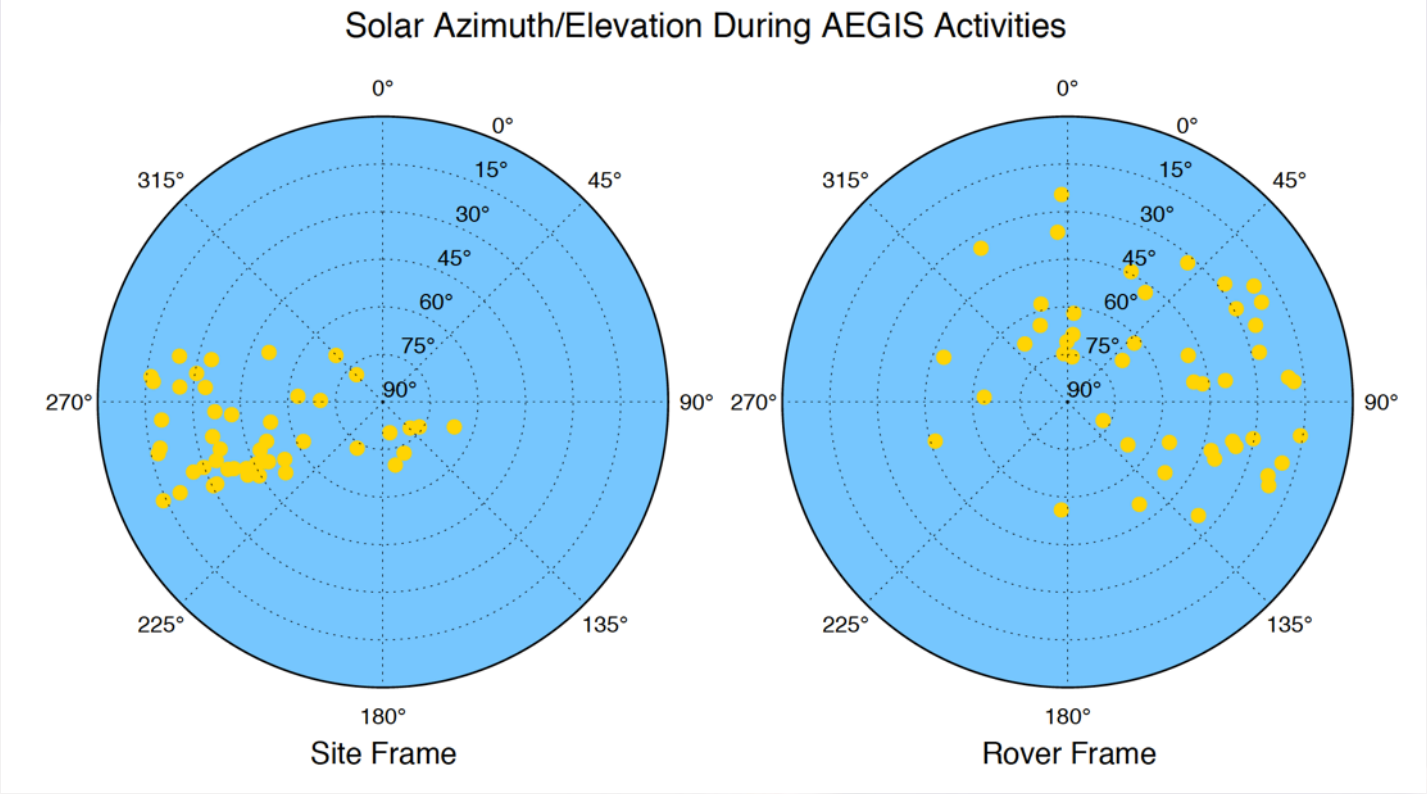


Figure from Pierre-Yves Meslin

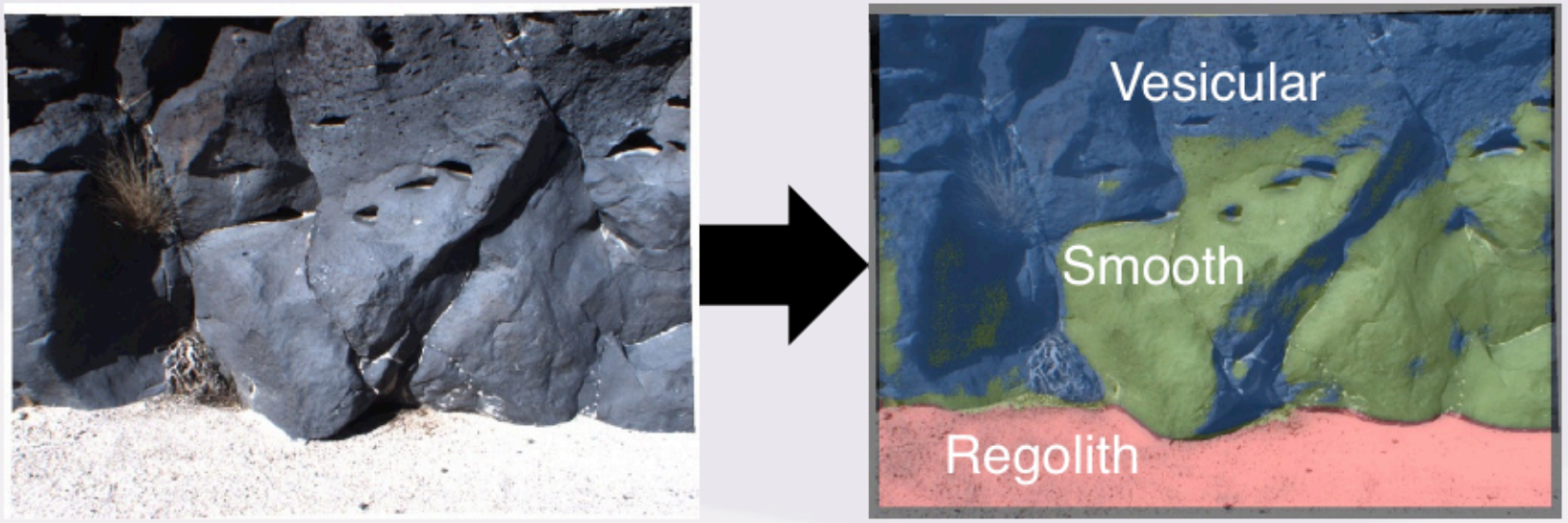
Lighting robustness

AEGIS autonomous targeting performs well across the range of lighting conditions we've seen

- Solar elevation and angle (time of day)
- Direction of lighting relative to the rover (and FOV)



TextureCam



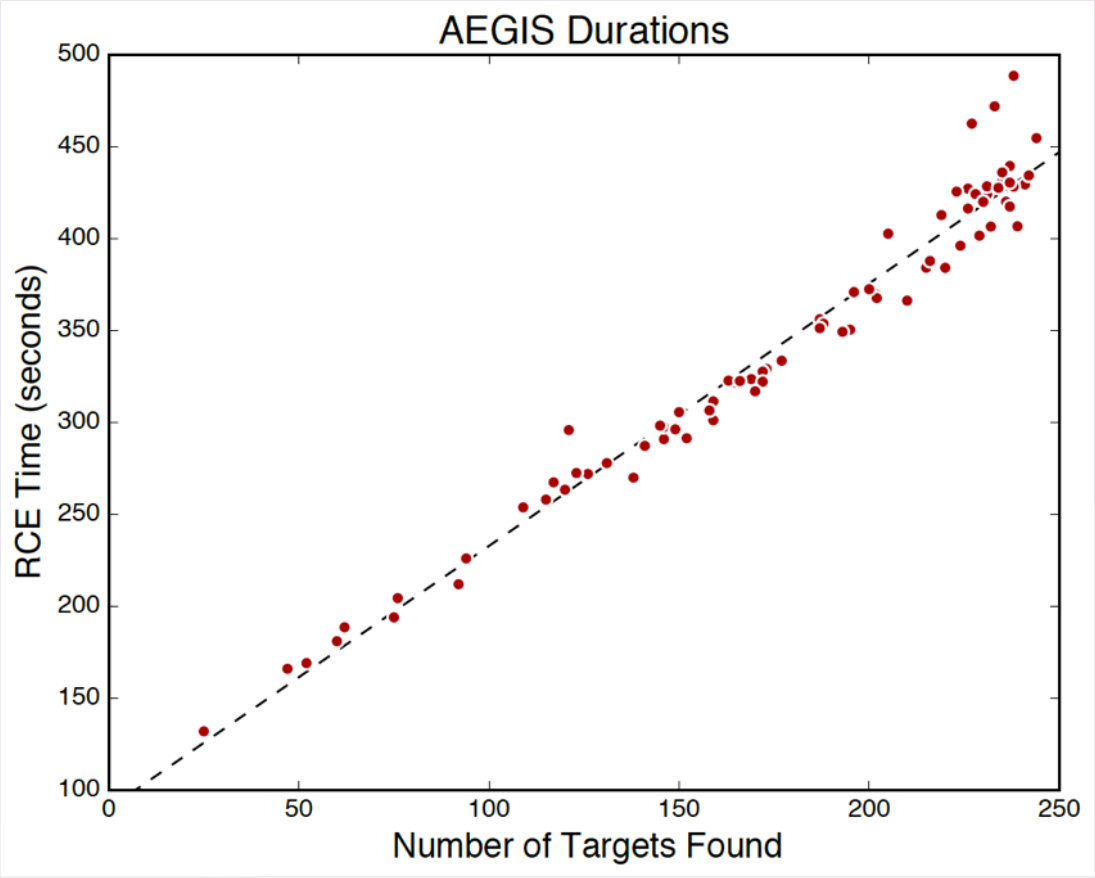
- A suite of software and algorithms for automatic classification of geologic surfaces
- Maps surfaces with texture channels which signify statistical patterns of image pixels
- To create a set of classifiers, uses a decision forest. Trees are created by training on a subset of pixels.

Run durations for NavCam

Run times on Curiosity flight RCE for `AEGIS_FIND_TARGETS_NAVCAM`

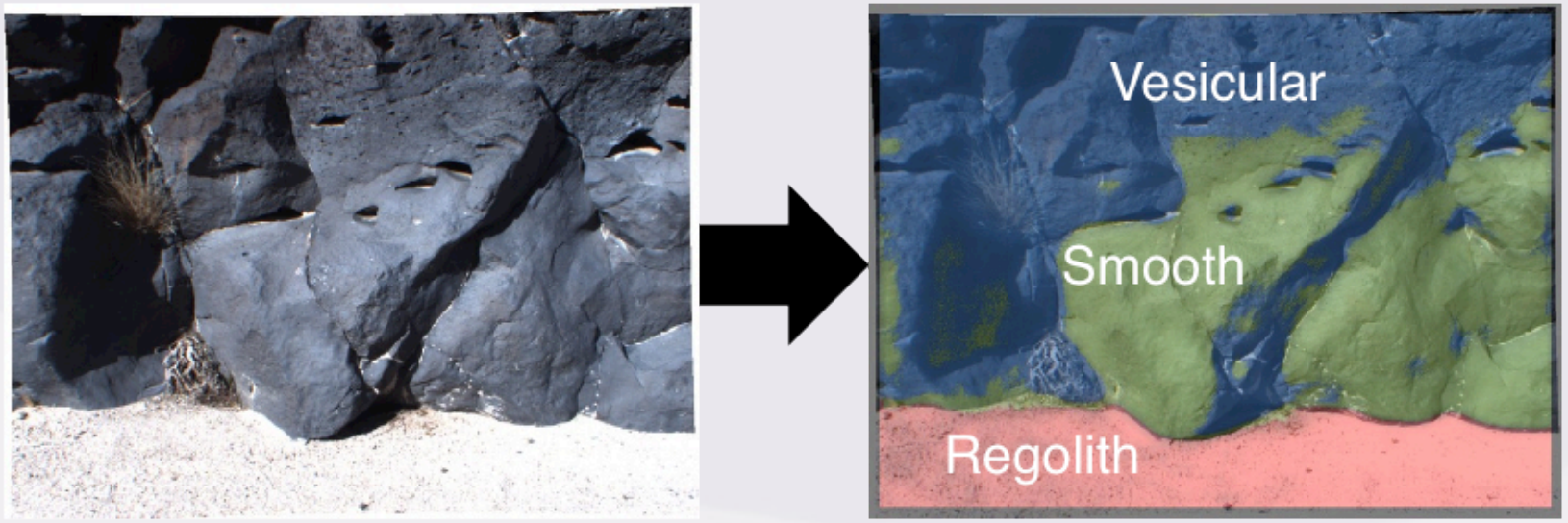
Roughly linear with number of targets found (90 s + 1.4 s per target)

- Current timeout is set to 600 s
- Includes a couple of actions not accounted here
- Should not reduce timeout much, if at all



Run times on Curiosity flight RCE for `AEGIS_FIND_TARGETS_RMI` are about 95-105 seconds

TextureCam



- A suite of software and algorithms for automatic classification of geologic surfaces
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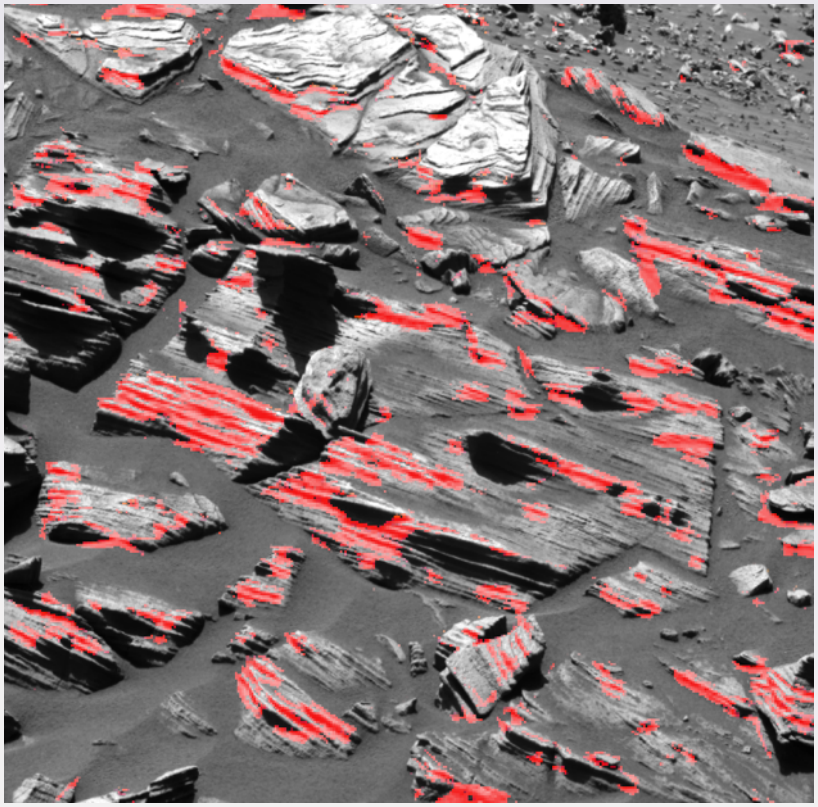
David R Thompson
Jet Propulsion Laboratory, California Institute of Technology
david.r.thompson@jpl.nasa.gov

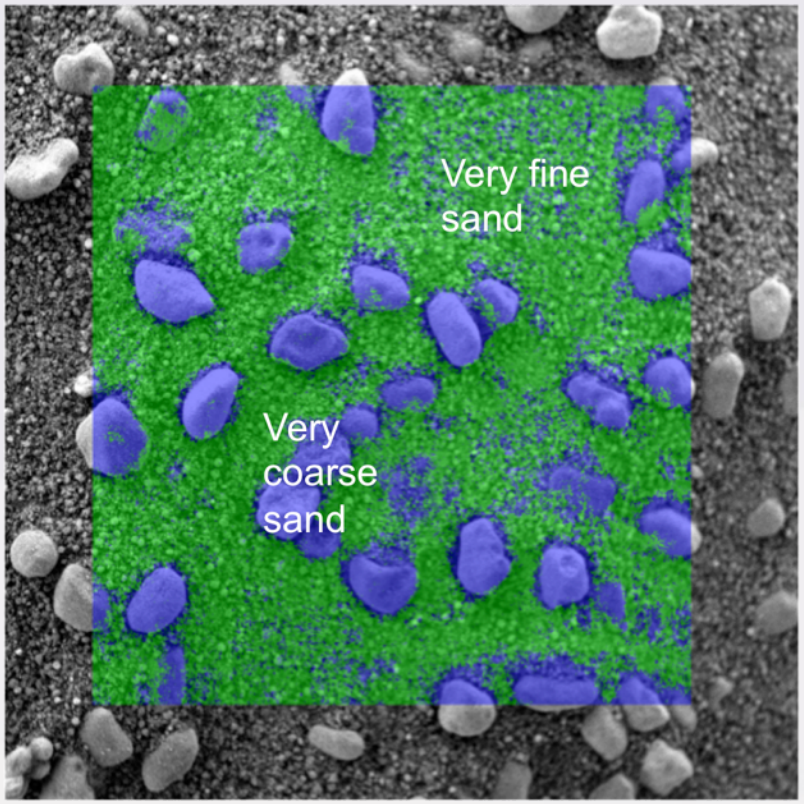
TextureCam is funded by the NASA Astrobiology Science and Technology Instrument Development program (NNH10ZDA001N-ASTID).

Other TextureCam applications

Layer detection, mapping



A “software sieve” for particle sizes



K. Wagstaff, D. R. Thompson, W. Abbey, A. Allwood, D. Bekker, C. Cabrol., T. Fuchs, K. Ortega. D.
Geophysical Research Letters 2013 (accepted, to appear)

Related Work in Rover Autonomous Science

Onboard Spacecraft Autonomy for Science:

- MER rover atmospheric event detectors (Castano, 2008)
  - Only downlink images that contain dust-devils or clouds

Mission Ground Planning Tools:

- MAPGEN MER rover automated planner (Bresina, 2005)
  - Used by MER operators for science activity planning
- MEXAR automated planner for ESA Mars Express (Cesta, 2007)
  - Used by Mars Express operators for data downlink planning

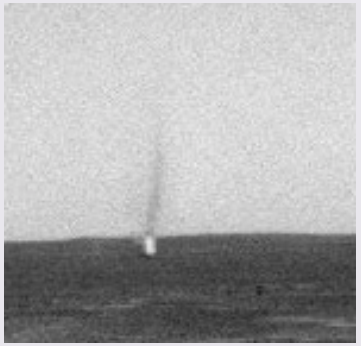
Image processing for geological features

- CMU Life in the Atacama (Smith, Wettergreen 2008)
- ESA ExoMars onboard analysis and planning (Pugh, 2010)

Image categorization and segmentation using decision trees (Shotton 2008; Moosman 2006)

Research on automated planning for robotic operations

- LAAS-CNRS autonomous robotic systems (Ingrand, 2007)
- ARC robotic site survey (Pederson, 2001) (Fong, 2008)
- ESA ExoMars onboard analysis and planning (Woods, 2009)



MER dust-devil detection

ESA ExoMars rover

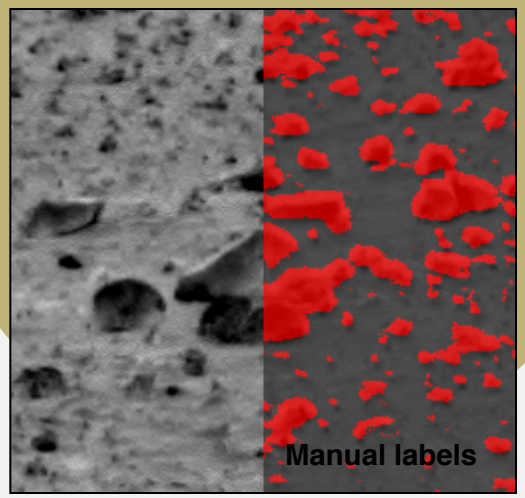
ARC site survey

AEGIS Target Detection using TextureCam

Maps surfaces with texture channels that signify statistical patterns of image pixels

A. In advance

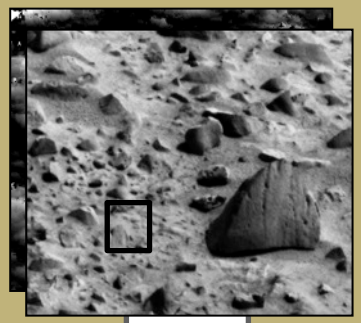
Build statistical models of geologic surface appearance using decision trees



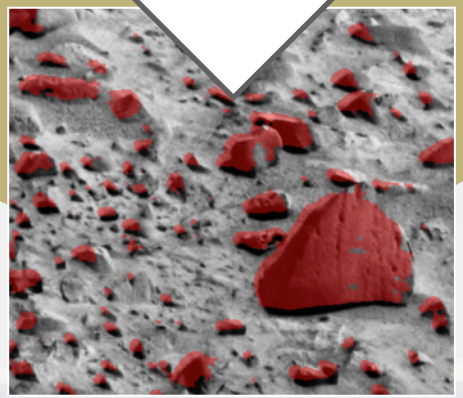
Original image: NASA/JPL/Caltech/Cornell

B. Online

Classify new image pixels



Analyze local patterns



Surface classification for new scene

PI: David R. Thompson, JPL